PB84-239425

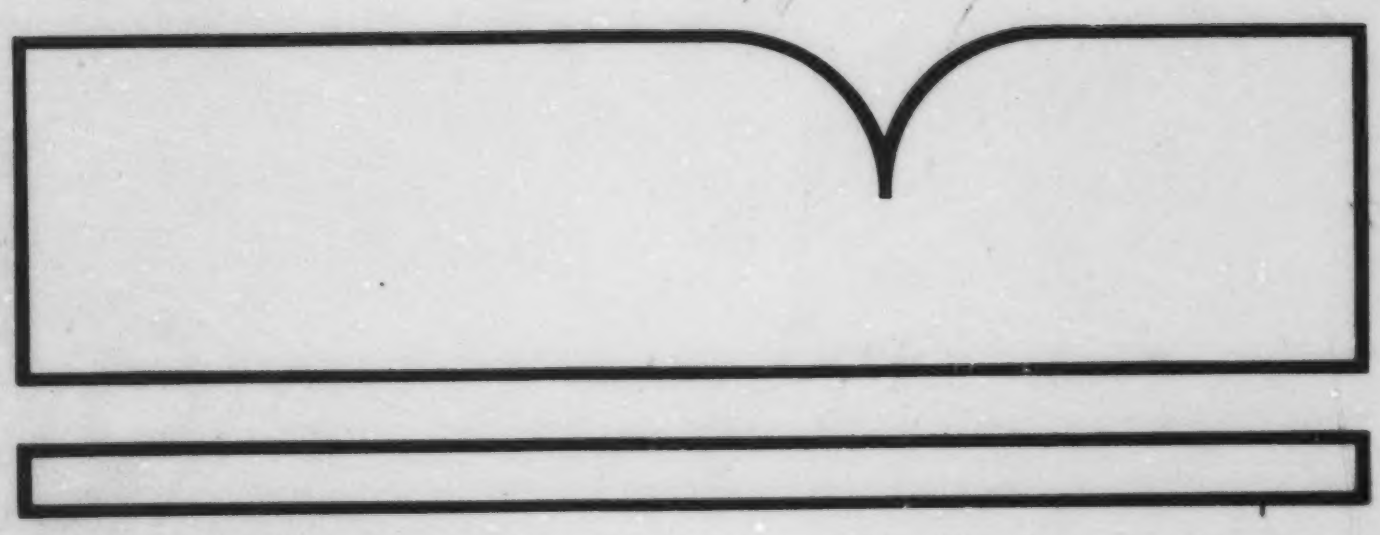
Demonstration of Vapor Control Technology for Gasoline Loading of Barges

MSA Research Corp., Evans City, PA

Prepared for

Industrial Environmental Research Lab.
Research Triangle Park, NC

Aug 84



U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-239425

EPA-600/2-84-140
August 1984

DEMONSTRATION OF VAPOR CONTROL TECHNOLOGY FOR GASOLINE LOADING OF BARGES

by

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EPA Contract No. 68-02-3657

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
EPA-600/2-84-140		PB84 239425

4. TITLE AND SUBTITLE	5. REPORT DATE
Demonstration of Vapor Control Technology for Gasoline Loading of Barges	August 1984
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
S. S. Gross	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
MSA Research Corporation Division of Mine Safety Appliances Evans City, Pennsylvania 16033	11. CONTRACT/GRANT NO. 68-02-3657
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
EPA, Office of Research and Development Industrial Environmental Research Laboratory Research Triangle Park, NC 27711	Final; 9/80 - 2/82 14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Samuel L. Rakes. For details, contact W. Gene Tucker, Mail Drop 54, 919/541-2746.

16. ABSTRACT The report gives results of a program to demonstrate a safe cost-effective way to control gasoline vapors emitted during barge loading. Refrigeration, carbon adsorption, oil absorption, and incineration were reviewed in terms of their safety, economics, and performance. Two barge terminals were used as the design basis for extending their existing truck loading vapor control systems (oil absorption and incineration) to include the barge loading facilities. Although, fabrication drawings were prepared for both terminals, the barge vapor collection system was installed only at the terminal using incineration. Arrangements were also made to lease a barge with vapor collection piping and add equipment to reduce the likelihood of barge explosion or overfill. However, before start-up of the demonstration, the program was curtailed. The system is still in place and could be considered for future field demonstrations.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Refrigerating	Pollution Control	13B	13A
Gasoline	Incinerators	Stationary Sources	21D	
Vapors	Carbon		07D	07B
Barges	Oils		13J	11H
Loading Procedures			15E	
Materials Handling Equipment			13I	

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS (This Report)	21. NO. OF PAGES
Release to Public	Unclassified	65
	20. SECURITY CLASS (This page)	22. PRICE
	Unclassified	

EPA Form 2220-1 (9-73)

NOTICE

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ABSTRACT

The objective of the program was to demonstrate a safe, cost-effective method of controlling gasoline vapors emitted during barge loading operations. Refrigeration, carbon adsorption, oil absorption, and incineration were reviewed in terms of their safety, economics and performance. Two specific barge terminals were used as the design basis for extending their existing truck loading vapor control systems (oil absorption and incineration) to include the barge loading facilities. While fabrication drawings were prepared for both terminals, the barge vapor collection system was installed only at the terminal using incineration. Arrangements were also made to lease a barge with vapor collection piping and add additional equipment to reduce the likelihood of barge explosion or overfill. However, before start-up of the demonstration, the program was curtailed. The system is still in-place and could be considered for future field demonstrations.

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SECTION 1

INTRODUCTION

Vapors emitted during the loading of gasoline into cars, trucks, and barges contribute to the formation of smog. Equipment is available which can control these vapors at truck loading facilities, as well as at larger gasoline retail outlets.

However, gasoline vapor emissions are not controlled at barge loading terminals because it has not been demonstrated that the more complex safety and design considerations have been adequately addressed.

This report discusses various vapor control technologies and their application to barge loading of gasoline. Two vapor control technologies were selected from the review. One was based on an oil absorption system which would recover the gasoline. The other was based on incineration, which has lower installation and operation costs, but no recovery.

Two existing terminals were used as the design basis for projected demonstration of the two control technologies. Both terminals had existing vapor control systems at the truck loading area. One terminal had an installed oil sorption system, with an additional uninstalled scrubber; the other had an installed incinerator. Each vapor control system had enough excess capacity to handle the vapors from the barge loading facilities.

It was decided to use the terminal with the incineration system as a demonstration site. The on-shore vapor collection system was connected to an existing incineration system with the corresponding safety and flow control equipment. A barge with vapor collection piping was leased. Equipment such as overflow alarms and flame arrestors were also purchased for installation on the barge to reduce the risk of overfill or explosion. Quality Assurance and Quality Control plans were also submitted to the EPA for approval. The QA/QC plan detailed the sampling, data collection and handling procedures.

Just before start-up, the program was curtailed.

During the study phase, 80 milligrams of hydrocarbons per liter was considered the level achievable using reasonably available control technology (RACT). This standard was applied to bulk loading at gasoline truck terminals. Subsequently, the EPA has issued a new source performance standard (NSPS) of 35 milligrams/liter. The actual emission level which may be chosen for barge loading will be based upon performance and cost considerations and not necessarily the 80 or more recently 35 milligrams/liter standard used at truck loading. The 80 milligrams/liter which existed at the time of the study was chosen only as a base line for cost and performance considerations and does not reflect the EPA's attitude towards a standard for barge loading.

SECTION 2

CONCLUSIONS

Of the vapor recovery systems, our calculations showed that oil absorption was the most economical followed by carbon adsorption, then refrigeration. However, the selection of a particular vapor control technique is dependent upon site-specific conditions.

While our calculations indicated a payback is possible with a vapor recovery system, in many cases the payback period is longer than the expected life of the recovery equipment.

Generally users felt that vapor recovery systems at truck loading facilities are not significantly more economical than incineration because of their higher capital and operating costs.

Prior EPA reports cite 80 milligrams of hydrocarbon per liter of gasoline loaded as the level achievable with reasonably available control technology (RACT) at truck loading. This is approximately a 90% control. Because of the lower effluent concentrations at barge loading, a 90% control level may be significantly below 80 milligrams. Existing vapor recovery systems can meet the 80 milligram emission level. However, if the emission concentration is significantly reduced, major upgrading of the vapor recovery equipment may be necessary.

Incineration may be the lowest cost (equipment and operating) approach to vapor control, especially with smaller terminals. However no payback is possible and there are additional safety considerations.

For the two installations discussed in the text, passive safety equipment, such as pre-tested and/or approved flame arrestors, would provide an adequate level of safety. Because of the short vapor lines and prior testing of the flame arrestors, active safety systems such as inerting, vapor saturation and dilution were not needed. However, in some cases, i.e., long vapor lines, active safety systems should be strongly considered.

It is significantly less expensive to equip a barge with a vapor collection system when constructed than to retrofit at a later date.

Because the terminal operator may not own or operate the barge, legal questions concerning safety and cost liability remain to be answered.

SECTION 3

RECOMMENDATIONS

If the control of gasoline vapors at barge loading faciities is desired by the EPA, conducting the field demonstration will be valuable for safety and economic analysis of an operational vapor collection and control system.

Vapor control systems were examined for two gasoline terminals. One system used vapor recovery, the other incineration. Demonstrations at both facilities would aid in comparing the two vapor control technologies.

The actual benefits of a vapor recovery system are difficult to measure because of the small fractions of gasoline recovered compared to the volume transferred. Continuous monitoring of the influent and effluent hydrocarbon concentrations would help the user realize the possible payback advantages of a vapor recovery system. In any case, the use of continuous monitoring instruments on the exhaust of the vapor control units should be considered. The performance of the units is unknown, unless monitoring is done on more than an occasional basis.

SECTION 4

STATEMENT OF WORK

The purpose of this program was to evaluate and assess the economics, performance, safety and general suitability of vapor control technology for controlling emissions from barges during loading of gasoline. MSAR was to select, in conjunction with the Project Officer, a demonstration vapor control system at an existing marine terminal engaged in loading barges with gasoline. In conducting this evaluation, MSAR was to perform the following tasks:

Task 1: Review and assess available information, including where appropriate, discussions with vendors and users on the performance, safety, costs and problems associated with vapor control systems used for volatile organic chemical emissions reduction. Three primary technologies were to be addressed: (1) vapor recovery, (2) incineration, and (3) carbon adsorption.

Task 2: Identify particular strengths, weaknesses and factors influencing performance, safety and economics of the three technologies as applied to control of gasoline vapor emissions during loading of barges.

Task 3: Select (with the concurrence of the Project Officer) a vapor control system to be demonstrated at a marine terminal which loads gasoline into barges. The selection was to be based on the outputs of Tasks 1 and 2. The vapor control system was to be acceptable to the U.S. Coast Guard insofar as safety is concerned.

Task 4: Provide for the use of a marine terminal and barge to participate in the demonstration of a vapor control system. The selected vapor control system was to be adapted to the facilities of the participating marine terminal and barge. The design was to be acceptable to the participants and approved by the pertinent government agencies. The marine terminal and barge(s) were to be selected with concurrence of the Project Officer.

Task 5. Fabricate, or procure, and install the pilot vapor collection and control system developed in Tasks 3 and 4 at the selected marine terminal. Operation and monitoring of the pilot vapor control system was to be for a period of six months or until completion of thirty (30) fill cycles, whichever occurred first. The safety, efficiency and operating characteristics of the pilot vapor control system were to be evaluated and documented. All vapors from the barge loading were to be collected, but only a side stream had to be recovered, or treated by the demonstration unit.

Task 6. Prepare a final report evaluating the vapor control system and an analysis of a scaled-up version for a total marine facility. The analysis was to include a basic design, operating characteristics, cost (capital, operating, discounted cash flow), safety and reliability.

During the program, the EPA decided to select and install two vapor control systems using oil absorption and incineration. Subsequent funding reductions eliminated the opportunity to build the oil absorption system. During Task 5 the demonstration of the installed incineration vapor control system was cancelled. Therefore, the report required in Task 6 will discuss the progress up to and including the installation of the on-shore and barge vapor collection and/or control system using incineration, and the detailed design of the oil absorption system.

SECTION 5

GASOLINE BARGE VAPOR CONTROL PROGRAM

CONTROL OF VOLATILE ORGANIC EMISSIONS - TASK 1

A letter requesting state-of-the-art information was sent to 85 manufacturers of vapor control systems or equipment. The names of these manufacturers were obtained from the Thomas Register. Replies were received from 45 of the manufacturers. Only 11 of the replies were useful in terms of vapor control. The following companies supplied some type of vapor control system:

McGill, Inc.	carbon adsorption
Vic Manufacturing	carbon adsorption
Vulcan	carbon adsorption
Hirt Combustion	incineration
Zink	incineration
Ecology Control	liquid absorption
Process Products	liquid absorption & incinceration
Ceca	refrigeration
Edwards Engineering	refrigeration
Kon-den-Solver	refrigeration
Tenney Engineering	refrigeration

Some replies also included information on vapor balance and vapor gathering systems.

The information search was limited to gasoline vapors although similar techniques are used for most volatile organic emissions. However, throughputs are small and usually only one or a limited number of compounds are controlled. Gasoline vapors have a large number of compounds, low flashpoint, and high throughput rates (especially at bulk terminals). These characteristics have created specific design requirements which in many cases have been discussed in the literature.

In addition to the manufacturers, users and government environmental personnel were questioned on their experience with gasoline vapor recovery units presently installed for truck loading operations.

The following technologies have been, or are presently being, used to recover gasoline vapors:

1. Incineration using propane as the pilot flame or saturation gas if the incoming gasoline vapors are within the explosive limits.

2. Refrigeration, which can be done at atmospheric pressure or under compression. Compression will allow the vapors to be liquefied at a higher temperature. However, the vapors should be saturated before compression. A number of companies at one time offered compression refrigeration systems. Because of high maintenance costs and poor payback, these systems are no longer marketed.

3. Carbon adsorption, where the vapors are adsorbed on activated carbon. After the carbon bed is saturated, the hydrocarbons are stripped from the carbon bed using vacuum.

4. Liquid absorption, which uses gasoline or a lean oil to scrub the vapors. In most cases the scrubbing liquid is chilled before entering the absorption column.

A total of three in-place barge vapor control systems were found. These are:

1. Corpus Christi Petrochemical (Corpus Christi, TX) has an on-shore benzene vapor control system using carbon. At the time of this report they did not have any barges retrofitted with a vapor collection system.

2. Marion Oil Company (Mobile, AL) has an on-shore gasoline vapor control system using incineration. They also have not been able to find a barge with a vapor collection system.

3. Union Carbide has a barge and an on-shore vapor collection system. This system is only dispersion system where toxic chemicals are sent up a tall stack. The vapors are not treated.

At the conclusion of Task 1, no functioning barge vapor control system was found. Although as noted above, there are on-shore or on-barge vapor collection and/or control systems, the two systems (on-shore and on-barge) have not been utiized together.

Apparently the companies are very reluctant to use a closed barge loading system for safety reasons. The only incentive cited by users for using a barge vapor control system was environmental. The vapor recovery systems have not proven that they are economical. Many companies still

consider incineration as the least expensive method of vapor control. Recovery methods such as refrigeration and carbon adsorption, while returning some product for credit, are considered more costly because of their higher purchase and operating costs.

Since no barge vapor control system was operational, inquiries about the performance, safety, costs and problems were based primarily on experience at truck loading terminals.

The performance of the vapor recovery units at truck loading facilities, which include carbon adsorption as well as refrigeration and oil absorption, was suspect. While manufacturers of these systems claim adequate performance (maximum emission of 80 mg/liter of gasoline loaded) some users complained they were not meeting the 80 mg/liter goal. Others did not really know the performance because few vapor recovery units had a hydrocarbon monitor on the outlet. It is felt that many recovery units will need further refinements if the emission level is reduced much below 80 mg/liter.

The performance of the incineration units at truck loading facilities has been satisfactory, according to users.

The safety of the vapor control units has been adequate according to users at truck loading facilities. However, the vapor concentration at truck loading is almost always above the flammable range. This may not be the case for barge loading.

A major environmental problem with the use of vapor control systems is providing a leaktight system. In addition, the vapor control system is usually the most complicated piece of equipment at a terminal. Therefore, maintenance may have to be done by outside contractors, increasing the operating costs. These problems seem to occur more often in vapor recovery or carbon adsorption than in the incineration units.

CONTROL TECHNOLOGIES APPLICABLE TO GASOLINE BARGE LOADING - TASK 2

No vapor control systems for gasoline loading of barges were found on record, but various methods were found in use at automobile service stations and bulk terminals for truck loading. These include vapor return, incineration, carbon adsorption, refrigeration and oil absorption. Some of the knowledge obtained from these applications is transferable to barge loading, but there are substantial differences in hydrocarbon concentration of the emitted air-vapor mixture, rate of loading, duration of loading and complexity of vent systems. Emitted vapor concentrations at service stations and bulk terminals, for most of the loading time, are over 30%, well above the flammable limits for gasoline of 1.5% to 7.6% by volume. During barge loading, the emitted vapor concentration has been found to be about 12% for uncleaned barges and 5% for cleaned barges over the first two-thirds of the loading time. In the last third, the concentration rises to levels approaching 55%[1]. During two-thirds of the loading time the concentration is close enough to the upper explosive limit that additional safety measures are needed in barge loading.

Loading rates and loading times vary considerably. At automobile service stations the rate and time are respectively 25 liters/min and 3 min. At truck bulk terminals, approximately 2300 liters/min, for 10 to 15 min, and an average given for barge loading, 16,000 liters/min for 190 min. Emission control equipment for barges must be considerably larger and under sustained operation for considerably longer periods. Their size is larger to a degree that dock space requirements on which they would be installed also becomes a factor.

Leaks in the vapor collection lines have been found to be a problem at truck terminals. At several bulk terminals vapor losses due to leakages has been as much as 30% of the total emissions[2-6]. One 10 cm diameter vapor collection hose is attached to a truck. In making barge connections there are 6 or 8 tanks with required outlet diameters of at least 15 cm. The problem of complete vapor collection from barges is considerably greater.

Barge Loading Operation

There may be from 3 to 10 tanks on the average barge, having a total capacity of 3190 m^3 (20,000 bbl). A header system is installed on the barge to direct the gasoline to the various tanks. A loading arm is used to attach the flanged delivery lines to the barge.

There is a vapor vent on each tank, and these are not hooked into a header arrangement as are the loading lines. Each vent line has its own flame screen and the vapor is simply discharged into the atmosphere. In fact, during the loading the ullage caps or manhole covers are opened for gauging and by our observation this is the general method of operation to relieve vapors, which simply are emitted into the atmosphere. Opened manhole covers provide a fail-safe system against overpressurization. Opened ullage caps provide a fail-safe system against vapor but not liquid overpressurization.

Table 1 gives some idea of barge sizes. The longest loading time is about 18 hours, from which loading rates can be roughly calculated. Loading rates do vary from terminal to terminal, but they are as high as possible in order to minimize the turn around time.

TABLE 1. LIST OF INSPECTED TANK BARGES AND TANK SHIPS
(U.S. Coast Guard)

Barge Length meters	Gross Tons	Cargo Capacity (m^3)	(bbl)
39	440	840	5,250
60	850	2,395	15,000
72	1,160	3,335	20,900
105	3,200	10,215	64,000
164	13,200	39,900	250,000

For basis of comparison, to evaluate different control systems, the "average" size barge and "average" loading rate[7] were used. The pertinent figures are:

Barge capacity	3190 m^3 (20,000 bbl)
No. of tanks	8
Loading rate	16,000 liters/min
Loading time	190 min
Emission rate	16 m^3/min
No. of loads/yr	300
Total gasoline loading	957,000 m^3/yr (6 million bbl/yr)

Nature of Vapor Emission

Average hydrocarbon concentration was assumed to be 15 mol %. About 3% of the vapors were assumed to be methane, ethane and a small amount of propane which are nonrecoverable by most systems in use. Composition of the vapor mixture varies with type of gasoline. Tables 2 and 3 give some concept of the constituents and their quantities. The data of Table 2 were taken from Run 9 of report EMD No. 77-GAS-19[3] and of Table 3 from reference 8.

TABLE 2. COMPOSITION OF GASOLINE VAPOR AT INLET TO PROCESSING UNIT

Hydrocarbon	Mol %	Compound	Mol %
Methane	2.68	2-Me-Pentane	4.58
Ethane	0.46	3-Me-Pentane	2.33
Propane	1.82	N-Hexane + $C_6^=$	2.07
Isobutane	13.87	Me-Cyclopentane	1.28
N-Butane + $C_4^=$	29.09	Benzene	0.90
2-Butenes	5.24	Cyclohexane	0.98
2-Me-Butene	0.61	C_7 Saturate	1.92
Isopentane	15.56	Toluene	1.26
N-Pentane + $C_5^=$	10.47	C_8 Saturate	0.06
2-Pentenes	4.09	Xylene	0.35
Cyclopentane	0.37		

Table 2 shows the wide range of molecular species found in the emissions although over 80% of the mixture consists of isobutane, n-butane, 2-butene, isopentane, n-pentane, 2-pentene, and 2-methyl pentane.

Table 3 presents an abbreviated version of Table 2. The mol fraction of vapors in air in this case is 0.419 with a total vapor pressure of 318 mm Hg. Concentrations as high as 0.60 mol fraction have been reported. This may be considered a saturated vapor-air mixture. ΔP is the partial pressure of each component, with total pressure 318 mm Hg. The objective achieved by any recovery system is to separate the 0.581 mol fraction of air from the mixture and to yield essentially a 100% hydrocarbon mixture, which when compressed to one atmosphere has partial pressures for each component

as given in column 5. The last column gives the vapor pressure of each component in pure state in equilibrium with the liquid.

TABLE 3. COMPOSITION OF MOST VOLATILE PORTION OF GASOLINE, REFERENCE 8

Hydrocarbon	mol fraction	%	P, mm Hg	P, mm Hg @ 1 atm	P, mm Hg @ 77°F
Propane	0.006	1.4	4.6	11	7,500
1-Butene	0.032	7.6	24.3	58	2,200
2-Methyl propane	0.029	6.9	22.0	53	2,600
n-Butane	0.174	41.5	132.2	316	1,800
1-Pentene	0.051	12.2	38.8	93	600
2-Methyl butane	0.077	18.4	58.5	140	750
n-Pentane	0.020	4.8	15.2	36	490
n-Hexane	0.030	7.2	22.8	54	150
	0.419	100	318	760	
Air	0.581				
	1.000				

It is apparent from these vapor pressure levels that the mixture, when recovered, will be in a vapor state at ambient conditions and cannot be readily recondensed to gasoline at ambient temperature and pressure. To return to storage, the vapor mixture must be reabsorbed into bulk gasoline, and in order not to change gasoline composition the ratio of vapor to gasoline should be at least 1:100.

For future reference and calculation purposes, the following liquid densities and molecular weights are used:

	Average Molecular Weight	Liquid Density g/cc
Gasoline	---	0.680
Vapor condensate	64	0.620
Secondary emissions	61	0.610
Diesel oil No. 2	250	0.775

Categories of Emission Control Systems

There are six general categories of emission control systems, based on design concepts, which need to be considered in making the evaluation. These are:

1. Thermal incineration
2. Compression - refrigeration - condensation
3. Compression - refrigeration - absorption
4. Carbon adsorption - liquid absorption
5. Refrigeration at low temperature
6. Lean-oil absorption.

In evaluating the above six categories, consideration was given to the following three factors, listed in decreasing order of importance:

1. Safety
2. Economics
3. Performance

All of the systems could meet the 80 mg/liter hydrocarbon exhaust vapor emission standard. This level was considered attainable under the reasonably available control technology (RACT) approach. The systems can operate well over 90% efficiency when correct operating procedures are followed and equipment is properly maintained. Although dependent upon the inlet concentration, 80 mg/liter corresponds to approximately 90% hydrocarbon reduction. In order to obtain the 90% reduction for barge loading where the inlet concentration is one-half to one-third that of truck loading, the emission rate would be one-half to one-third of 80 mg/liter.

Thermal Incineration

By this method, the gasoline vapors are burned to CO_2 and H_2O at efficiencies of 99.9% of all of the hydrocarbon emissions. Some risk is involved in operation of the incinerator since the vapor concentration in the emissions from barges would be near the upper explosive limit for a large part of the loading period[1]. In some systems used at truck terminals, the emissions are saturated with gasoline spray, propane or natural gas to insure the hydrocarbon concentration is well above the upper explosive limit. Saturation adds considerably to the incineration cost.

Some suppliers of incineration systems at truck loading facilities no longer specify a saturation step. Only flame arrestors are used to prevent flame propagation back through the piping system. In this situation, propane or natural gas is used only as a pilot flame. In these systems the gasoline vapors will not ignite or sustain combustion below the lower flammable limit of 1.4%.

Incineration systems also use blowers which add to the problem of over or underpressurization of the barge. Incineration systems for truck loading facilities may not be directly applicable to barge loading due to differences in the vapor concentration and the pressure/vacuum ratings of a tank truck versus a barge.

Systems Using Compression

Systems (2) and (3) were eliminated from further consideration because of the compression stage in the overall recovery process. The vapor concentration of the incoming vapor-air mixture should be safely above the upper explosive limit to avoid possible ignition of the vapors during compresssion. Vapor concentrations emitted from barge loadings are too close to the 7.6% upper explosive limit to permit operation of a compression system with any assurance of safety without presaturating the emitted vapor-air mixture. The saturator adds considerably to the cost and also the complexity of the overall recovery system.

In addition, compression systems which can be found at truck loading facilities are no longer marketed. The safety problems as well as high maintenance and low payback did not justify consideration of this type of vapor control system.

Carbon Adsorption-Absorption

A much closer examination of the advantages and disadvantages of systems 4, 5 and 6 is necessary before any one of the three can be given preference. In order to compare merits of these systems, it is desirable to examine their operations in some detail.

Figure 1 presents a diagram of the carbon adsorption-liquid absorption vapor recovery system manufactured by McGill, Inc. It has two carbon adsorbent beds which are alternately on adsorption and desorption in fixed time intervals. Liquid absorption in the scrubber returns the recovered vapors to storage.

During the adsorption phase of the cycle, the hydrocarbons in the air stream penetrate the pore structure of the carbon and thereby are removed from the air stream. The capability of the carbon to retain the hydrocarbons depends on the molecular size, temperature and vapor pressure. Larger molecules are adsorbed more strongly than smaller ones. Low temperatures and high pressures favor increased adsorption. Conversely, raising the temperature and lowering the pressure causes desorption of the hydrocarbons previously adsorbed. Also, smaller molecules are more readily desorbed than larger ones. In general, small molecules such as methane and ethane are too weakly adsorbed for carbons to be effectively used in their recovery while larger molecules, larger than octane, are increasingly more difficult to desorb. The molecular size range, where carbons are most effective in recovery applications, extends from propane to octane.

The carbon bed, after the fixed adsorption time interval, can be regenerated by desorbing the hydrocarbons. This can be done by raising the carbon bed temperature or by reducing the pressure with vacuum. The latter method has proven to be safer and more effective; the pressure in the spent adsorber is reduced to 25 mm Hg by the end of the regeneration period.

On repeated adsorption-desorption cycles, the full capacity of the carbon is not used because it would be uneconomical to desorb the carbon to its original capacity. Instead, the carbon is only partially regenerated; the partial capacity that is thus utilized is the "working capacity." A "heel" of hydrocarbons is retained in the carbon. If the heel gradually increases, as by accumulation of large size molecules and by ineffective regeneration, the working capacity is ultimately lost and the carbon must then be replaced.

The desorbed vapors are reabsorbed into the supply gasoline stream in the separator and scrubber and by this route returned to gasoline storage. The gas mixture passing through the separator and scrubber con-

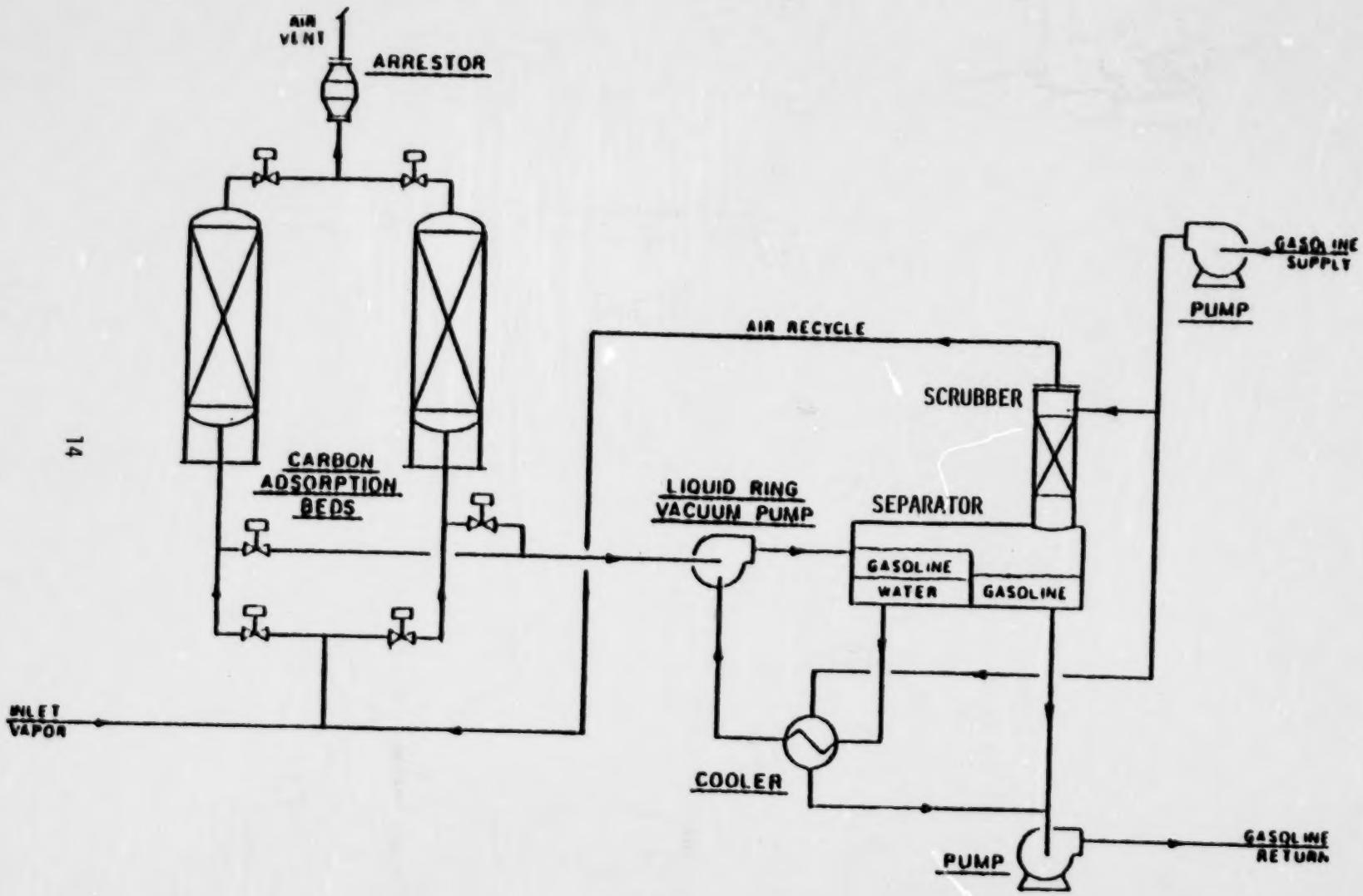


FIGURE I ADSORPTION-ABSORPTION GASOLINE RECOVERY SYSTEM

tains air which, now saturated with gasoline vapor, is recycled through the on-stream carbon bed.

The vacuum pump is cooled with recycled glycol which is in turn cooled by the recycled gasoline stream.

During periods when no gasoline is loaded, the beds are further desorbed under vacuum with a small sweep of warm air. This operation can last up to four hours, but one hour is the usual practice. it reduces the heel and thereby helps maintain the working capacity at the design level.

When the bed is new or has been well regenerated, the secondary emissions are very low. McGill states that secondary emissions are readily maintained below 30 mg/liter. However, since the carbon bed does not readily adsorb methane and ethane, the levels of these compounds in the gasoline vapors has a strong influence on the secondary emissions from the carbon beds. It is highly effective for control of toxic vapors such as benzene. However, adsorption is a "capacity" process, and when the capacity is exceeded the breakthrough concentration rises rapidly.

McGill recommends (telephone communication) their Model 1004 for continuous loading of barges under conditions previously specified, i.e., 16,000 liters/min, etc. Such a unit has 4140 kg of carbon in each adsorber and the recycled gasoline flow rate is 825 liters/min. On the basis of these data some approximations can be made on the inner operations of the system. Taking a 15 minute interval (which may not be optimum for this application) the total air-vapor flow entering the carbon bed would be:

$$16{,}000 \text{ liters/min} \times 0.001 \text{ m}^3\text{/liter} \times 15 \text{ min} = 240 \text{ m}^3$$

To this total flow, 11 m^3 must be added under steady state conditions due to the recycle from the scrubber, making the total flow to a bed on each cycle approximately 251/m^3.

The 11 m^3 consists of 6.5 m^3 of air retained in the spent bed, which is pumped out during desorption. On passing through the scrubber, it picks up 4.5 m^3 of gasoline vapor assuming 40 mol % saturation. The 6.5 m^3 was estimated on the basis of 4140 kg carbon with bulk and real densities of 0.48 g/cc and 2.14 g/cc, respectively, and allowing for (1) 0.9 m^3 dead space at each end of the bed, (2) adsorbed liquid volume within the pore size, and (3) partial filling of the void space with 12% unadsorbed vapors.

Of the 251 m^3 entering the bed in 15 minutes, 28.8 m^3 is vapor (12% x 250) from the barge and is adsorbed, 4.2 m^3 is vapor from recycle and is readsorbed, 6.5 m^3 is air from recycle and is retained in bed, and 211.5 m^3 passes through the bed. of the total air entering the bed (211.5 m^3), 3% is retained and recycled.

During desorption, 33 m^3 of vapor and 6.5 m^3 of air, an average 83 mol % enter the separator and scrubber. The composition of the air-vapor mixture, however, changes continually. The more volatile compounds release

more rapidly from the carbon than the less volatile ones. There is some tendency for compounds to come off individually, and because of this, the vapor pressures of some of the compounds exceed the saturated vapor pressures and condensate forms in the separator. The others are absorbed in the scrubber. Thus, during the air-vapor passage through the scrubber, 28.8 m^3 or 73.8 kg of gasoline vapors are condensed and 11.2 kg are recycled and readsorbed.

On the basis of these figures the working capacity comes to 2.0%,

$$100 \times (73.5 + 11.2)/4140 = 2.0\%$$

This working capacity is based on the total bed weight, but the total bed is not involved in each adsorption-desorption cycle, hence the true working capacity is greater than 2%. On new carbon the active region of the bed is near the influence end and as higher molecular weight molecules accumulate in the bed, the active region in the bed gradually drifts toward the effluent end. The location of the active region can be determined by temperature changes in the bed. Temperature rise can be as high as about 20°C, but varies considerably with vapor concentration. When the active region approaches the effluent end of the bed, it is then time to change the carbon. If use of the carbon beds is continued beyond this point, a bleed-through of vapors will occur before the fixed time period of the adsorption phase is completed. From this analysis, it is apparent that the bed must be sized according to total amount of vapor that needs to be controlled in some given length of time.

McGill gives a three-year warranty on their carbon bed, but expects them to last 20 years. For this application, a three-year operating time would involve about 15,000 cycles. Laboratory tets have been carried out[8] which substantiate 2% to 3% working capacities to 1,000 cycles. McGill pilot plant tests (private communication) showed that from about 1,000 cycles the working capacity stayed relatively constant at about 2% up to 100,000 cycles when the experiments were terminated. In this case the pilot system operated on a 6 minute cycle time. The 100,000 cycles represent over 20 years operation under a relatively heavy loading schedule.

If the beds should need replacement in three years, the replacement at $2.20/kg purchase and reloading costs would be $6,000/yr. When compared to yearly operating costs, to be given later in this report, this amount is not excessive.

In Model 1004 unit, the gasoline supply rate is 825 liters/min or approximately 8,400 kg in 15 min. About one-half of this flow goes through the scrubber, the rest is used to cool the vacuum pump. From the carbon bed a total of 73.5 kg of vapors are ultimately absorbed in this gasoline stream. The ratio of supply gasoline to vapor condensate comes to approximately 100 to 1. A large ratio is needed in all recovery systems where the product is recovered in vapor form so that the gasoline can adequately reabsorb the product.

Edwards Engineering [9] claims that the large flow of gasoline through the separator aspirates the air entering the separator and carries it to the gasoline storage tank. If this aspirator action draws more than 6.5 m^3/15 min or 0.43 m^3/min, air flow can be reversed through the scrubber and vapors that were intended to go to the on-stream adsorber are drawn directly into the gasoline stream. The carbon system thereby would operate in part as a vapor-return system. McGill, however, has a device in the separator that prevents the formation of a vortex, without which aspiration cannot occur.

The carbon adsorbers for the 1004 model are 3 m in diameter by 3.3 m tall; requiring a concrete pad 3.6 m x 7.8 m. The support part of the unit is skid mounted and can be contained on a concrete pad 3.6 m by 6.9 m. Maximum height is at the scrubber where it is about 6 m. The two pads should be kept close to each other to maintain maximum efficiency during regeneration.

The carbon adsorption system can be used at barge loading terminals. However, because of the size of the pad (3.6 m x 7.8 m), the unit may have to be installed some distance from the dock area. As a result, there may be long vapor lines which adds to the cost and decreases overall safety.

Because of the vapor profile of the barge effluent, care must be taken when the gasoline vapor concentration increases from 12% to 50% towards the end of the loading cycle. Because of the rapid increase in vapor concentration within a short period of time, it would be possible to overload the carbon beds.

McGill does not supply instrumentation with the carbon unit so that continuous measurement of influent and effluent vapor concentrations cannot be performed. They suggest that the user can visually see if breakthrough has occurred.

Refrigeration System

Edwards Engineering and Tenny Engineering manufacture refrigeration systems for control of gasoline vapor emissions. The information presented here was obtained from discussions with Edwards Engineering and from their literature. They have two types of refrigeration systems that could be used for barge loading, one in which methylene chloride is used as the heat transfer medium and the other in which the refrigerant is pumped directly to the condenser. They recommend the latter type, and, for the magnitude of the application being considered in this report, they further recommend their Model DEV 4800 P. This unit is sized for continuous operation at the 16,000 liters/min loading level.

Figure 2 presents a schematic diagram of this vapor recovery unit. The separation of air and gasoline vapors is effected by cooling the gas mixture down to temperatures as low as -73°C. All vapors except methane and ethane condense or are absorbed in the condensed phase to varying degrees at

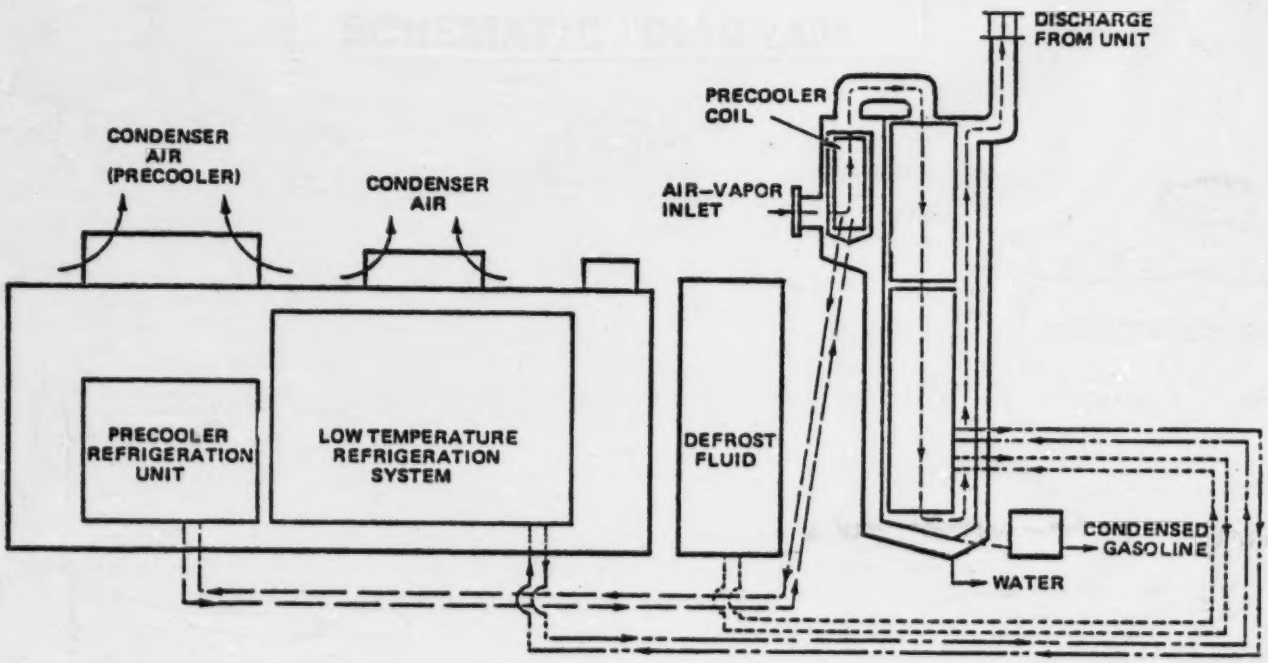


FIGURE 2 HOW THE EDWARDS HYDROCARBON VAPOR RECOVERY UNIT WORKS

temperatures in the -62°C to -84°C temperature range. Condensed vapors drop out as liquids and drain to the bottom of the condenser as shown in the diagram.

Since gasoline vapor emissions invariably contain water vapor, the emission vapors are cooled first to 1°C to remove as much water as possible by passing the air-vapor mixture through the pre-cooler. The air-vapor mixture now entering the -62°C to -73°C part of the condenser still contains moisture at 5 mm Hg vapor pressure. At approximately 16 m^3 inlet gas flow rate, the calculated amount of frost than can form on the cold cooling coils during the (190 min) barge loading comes to about 16 kg. This layer of frost reduces heat transfer and is remelted after each loading by heating the coils with the defrost fluid. The defrosting is completed in 30 to 60 minutes, approximately the time to ready the next barge for loading.

Vapor recovery by refrigeration is an equilibration process in contrast to recovery by adsorption which is a capacity process. The non-methane, non-ethane effluent from a new or well regenerated carbon bed approaches zero concentration up to the time when the adsorption front penetrates the effluent face of the bed. Then, in time, the concentration increases rapidly until it equals the influent concentration. The effluent from a condenser approaches a steady state or equilibrium concentration, the level being determined by the temperature at the effluent end of the condenser and composition of the vapor mixture.

Tables 4, 5 and 6 present gasoline vapor compositions and vapor pressure data which can be used to predict the relative effectiveness of a condenser at various effluent temperatures. Table 4 gives a mol fraction composition that is representative of gasoline vapor mixtures at 42 mol % concentration. Columns 3, 4 and 5 record the saturated vapor pressures of each hydrocarbon when in pure state. Whenever the vapor pressure of any of the hydrocarbons exceeds it, saturated vapor pressure condensation occurs. Those hydrocarbons towards the bottom of the table condense sooner or more rapidly than those above and form a liquid phase which becomes an absorbent for the more volatile hydrocrbons. The advantage of this fact is taken in the condenser design in that the refrigerant at its coldest temperature enters the condenser at the bottom and the air-vapor mixture enters at the top. A counter-current effect is produced. The liquid film forms at the upper part of the condenser and as it moves downward, absorbs some of the more volatile hydrocarbons. Thus the residual vapor concentration is considerably lower than would be predicted on the basis of the saturated vapor pressures.

Table 5 gives estimates of the effluent vapor pressures and concentration when influent concentratin is 15 mol % but correction is made for absorption of the volatile hydrocarbons. Table 6 gives the estimates when influent concentratin is 42 mol %. Both tables are presented since two-thirds of the barge loading time may occur at 12 mol % and one-third at approximately 40%.

TABLE 4. PROBABLE COMPOSITION OF GASOLINE VAPORS AND THE VAPOR PRESSURE OF EACH HYDROCARBON IN PURE STATE AT -84°C (-120°F), -73°C (-100°F) and -65°C (-85°F)

Hydrocarbon	Mol Fraction	Saturated vapor pressure, mm Hg @ -84°C	@ -73°C	@ -65°C
Propane	0.006	74	150	240
1-Butene	0.032	8	20	35
2-Methyl propane	0.029	12	28	50
n-Butane	0.174	5	14	26
2-Pentene	0.051	0.5	1.9	4.1
2-Methyl butane	0.077	1.0	2.5	5.2
n-Pentane	0.020	0.5	1.4	3.0
n-Hexane	0.030	0.1	0.4	0.7
Hydrocarbon	0.42			
Air	0.58			

TABLE 5. ESTIMATE OF INFLUENT AND EFFLUENT VAPOR PRESSURES WHEN INFLUENT CONCENTRATION IS 0.15 MOL FRACTION

Hydrocarbon	Mol Fraction	Influent @ 25°C, mm Hg	Effluent, mm Hg @ -84°C	@ -73°C	@ -65°C
Propane	0.0021	1.5	1.5	1.5	1.5
1-Butane	0.0114	9	8	9	9
2-Methyl propane	0.0104	8	8	8	8
n-Butane	0.0621	47	5	14	26
2-Pentene	0.0182	14	0.5	2	4
2-Methyl butane	0.0275	21	1.0	2.5	5
n-Pentane	0.0071	5.5	0.5	1.5	3
n-Hexane	0.0107	8	0.1	0.5	0.5
Hydrocarbon	0.1495	114	25	39	57
Air	0.8505	546	735	721	703
HC Conc, %	0.15	15	3.3	5.1	7.5
Conc, mg/liter	--	390*	72*	111*	163*

*Molecular weight of influent vapor mixture used is 64 and of effluent, 53.

TABLE 6. ESTIMATE OF INFLUENT AND EFFLUENT VAPOR PRESSURE WHEN INFLUENT CONCENTRATION IS 0.42 MOL FRACTION

Hydrocarbon	Influent @ 25°C, mm Hg	Effluent, mm Hg @ -84°C	@ -73°C	@ -65°C
Propane	4.5	4.5	4.5	4.5
1-Butane	24	8	20	24
2-Methyl propane	22	12	22	22
n-Butane	132	5	14	26
2-Pentene	39	0.5	2	4
2-Methyl butane	58	1.0	2.5	5
n-Pentane	15	0.5	1.5	3
n-Hexane	23	0.1	0.5	0.5
Hydrocarbon	317	32	67	89
Air	443	728	693	671
HC Conc, %	42	4.2	8.8	11.7
Conc, mg/liter	1,100*	91*	191*	254*

Molecular weight of influent vapor mixture used is 64 and of effluent, 53.

According to results in the bottom line of Table 5, the vapor concentration decreases from 390 to 72, 111 or 165 mg/liter,when the temperature is decreased from 25°C to -84°C, -73° or -65°C, respectively. In Table 6, the respective concentrations are 1,100 to 91, 191 and 254 mg/liter. From day-to-day operations of the systems, it has been recorded that in the -73° to -65°C temperature range and 40 mol % concentration, the effluent concentration is below the 80 mg/liter concentration level. At lower mol %, the effluent concentration is progressively lower. Absorption of the more volatile hydrocarbons in the condensate of the less volatile hydrocarbons is a significant factor.

The relative concentration numbers in the bottom lines of Tables 5 and 6 give an indication of the effect of overload (due either to higher influent concentration or increased loading rate) on the effluent vapor concentration. For example, if loading rate is increased so that effluent temperature increases from -73 to -65°C, the effluent concentration increases from 191 to 254 mg/liter; i.e., by 33%. The effectiveness of the refrigeration system decreases gradually and by relatively small amounts as overloading occurs. Refrigeration efficiency can be maintained by increasing power input into the refrigeration plant up to maximum capacity of plant. Rapid changes in the gasoline vapor concentration should therefore not adversely affect the unit.

Power requirements for the refrigeration system are larger per unit time than for other recovery systems because the air-vapor mixture is cooled to considerably lower temperatures. Power requirements were calcu-

lated for barge loading at condenser effluent temperatures of -84°, -73° and -65°C when vapor concentration was 15 mol % for 2/3 loading time and 42 mol % for 1/3 loading time. A 10% heat gain was assumed during loading time. The power requirements for the three temperatures were 130 KW, 123 KW and 119 KW. AT 35 mol % influence concentration, Edwards Engineering has measured 140 KW which also includes other power requirements of the total system. For equivalent loading rates and concentrations, the carbon recovery system operates at 61.7 KW and the oil absorption system at 29.3 KW. However, the latter two operate a longer time per barge loading and thereby nullify their apparent advantage as represented by their lower KW rates.

The dimensions of the skid mounted refrigeration unit are 3.1 m wide, 13.3 m long and 3 m high. The condenser is about 0.9 m by 0.9 m by 5.4 m high. It can be mounted on the skid or separated by a considerable distance from the support system. This feature adds to the versatility of the unit since the relatively small condenser can be located on the dock where space may be limited. If any concern exists regarding safe operation of the support system, it can be removed to a safe distance from the dock and also from storage tank areas.

Edwards Engineering supplies instrumentation with the unit to determine influent and effluent vapor concentration on a continuous basis. A gasoline meter is also supplied with the unit which measures the cumulative amount of product collected in any given time period.

Lean-Oil Absorption

Figures 3 and 4 present diagrams of lean-oil absorption units manufactured by Ecology Control (now called Vatrol) located in Houston, TX. These units are in use to control gasoline storage tank and truck emissions due to breathing or loading, which can be near the 16,000 liters/min rate.

The air-vapor mixture at about 32°C enters the scrubber-absorber, shown on the left side of the drawing. Lean oil (Diesel No. 2) cooled to 4°C is drawn from the lean-oil tank and sprayed downward through the scrubber, counter-current to the air-vapor mixture flow. As in all vapor recovery systems, methane, ethane and some propane, pass through the system and are vented into the atmosphere. Butane and heavier hydrocarbons are absorbed into the oil with increasing effectiveness with increased molecular weight. the enriched oil from the scrubber is pumped into the rich-oil tank.

The rich-oil is then regenerated by heating to 93°C at 150 mm Hg absolute pressure, the final step occurring in the strip vessel at the right side of the drawing. The stripped or lean-oil is cooled to 40°C and pumped to the lean-oil storage tank.

The gasoline vapors being flashed off in the stripper at 150 mm Hg and 93°C can be (1) compressed and cooled to condense the vapors as in

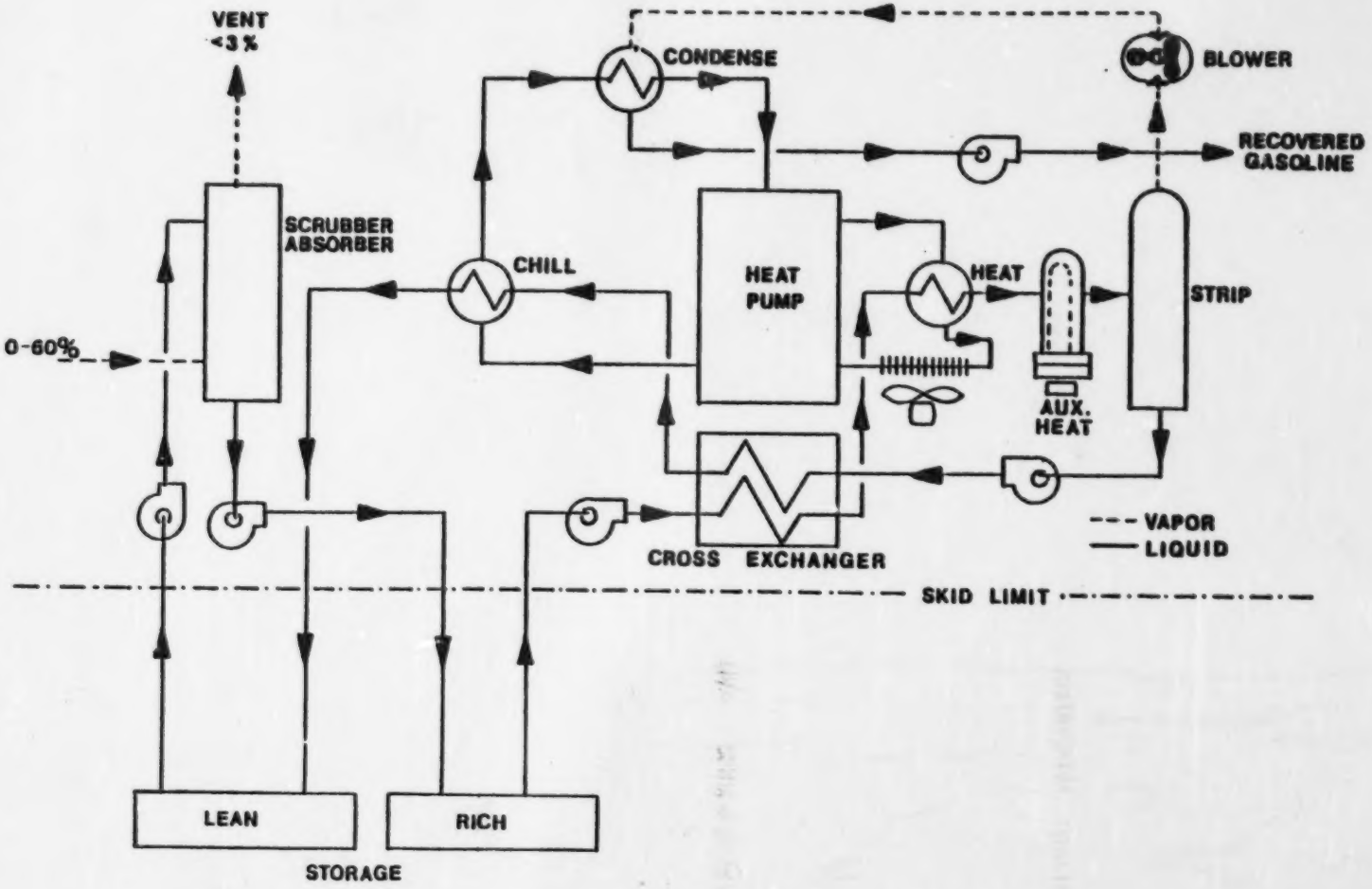


FIGURE 3 - LEAN OIL ABSORPTION

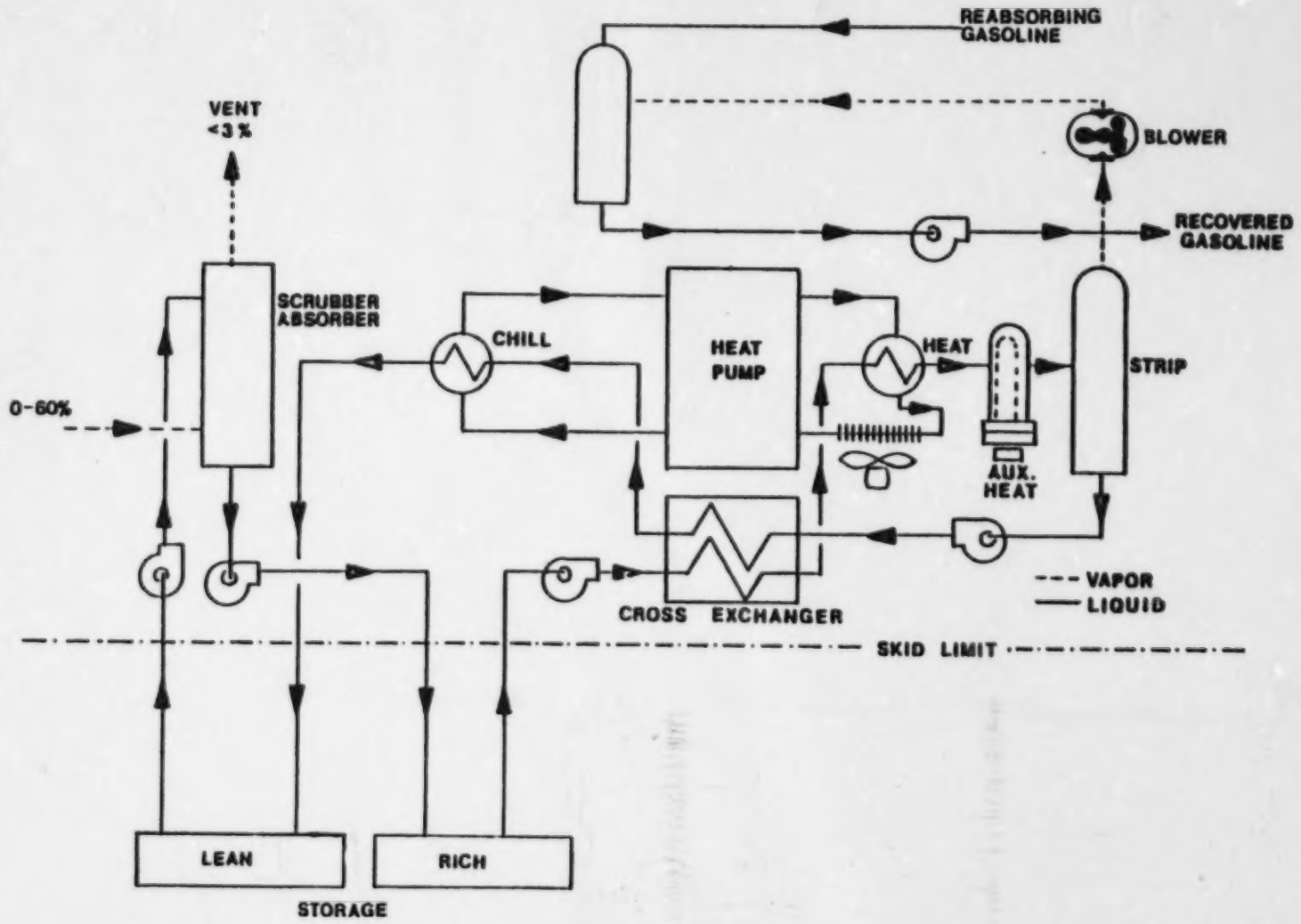


FIGURE 4 - LEAN OIL ABSORPTION

Figure 3, and then blended into gasoline, or (2) compressed to 400 to 500 mm Hg absolute pressure and absorbed into gasoline in a packed reabsorption column as in Figure 4.

The overall dimensions of the skid mounted portion of the system are 5.4 m wide, 6 m long and 4.5 m high. The scrubber-absorber is a 1 m diameter cylindrical tank 4.5 m high with monofilament internal packing for mist separation and absorption. Ground wires crossed through the bed eliminate buildup of static charges. The scrubbing liquid is spray distributed. A series of baffles distributes the incoming vapor through the scrubber.

The scrubber-absorber can be mounted separate from the support system by a considerable distance as was the case with the refrigeration unit. This adds to the versatility of the unit where (1) loading dock space is limited or (2) if there is any concern regarding operating risks. The support system can be removed to a safe distance or out of the way from the dock and storage tank areas.

The effectiveness of the oil-absorption unit depends on the amount of oil versus the amount of gasoline vapor passed through the scrubber and the purity and temperature of the diesel oil. To attain economical operation, the oil input rate is adjusted to the vapor concentration to maintain a secondary emission below 80 mg/liter. Based on experience, the oil flow rate required is 95 liters/min (73 kg/min) when vapor concentration is 12 mol % and 228 liters/min (175.5 kg/min) when vapor concentration is 60 mol %. Condensate condentration in the rich oil comes to 8.0 weight % when vapor concentration is 12 mol % and 12.3 weight % when vapor concentration is 60 mol %.

Under test conditions, at 12 mol % vapor concentration the secondary emission concentration has been measured at approximately 2.9 mol %, disregarding methane and ethane and at 60 mol % vapor concentration the secondary emission concentration has been measured at 2.7 mol %. The calculated mg/liter of secondary emissions are 75 at 12 mol % and 69 at 60 mol %.

Absorption of gasoline vapors in diesel oil should obey Raoult's law if all the factors were known. For a solution consisting of a volatile solvent and nonvolatile solute, Raoult's equation has the form

$$p = k \frac{n_1}{n_1 + n_2} kx$$

Here n_1 is the number of mols solvent and n_2 the number of mols solute in the solution; p is the vapor pressure of the solvent over the solution; k is proportional to p_o, the vapor pressure of the pure solvent; x is the mol fraction.

When the heat of solution of the solute is equal to the heat of condensation of the solvent $k = p_o$, if it is higher $k<p_o$ or lower $k>p_o$.

Gasoline absorption involves a multi-component solvent in a multi-component solute. In this case, the diesel oil is considered the solute. The equation would have the following form for each hydrocarbon component, i.e.:

$$p_i = k_i \frac{n_1}{n_1 + n_2 + \ldots . n_n + n_d}$$

where n_d is the number of mols of diesel oil. The total emission vapor pressure is then the sum of the gasoline vapor components, $p_1 + p_2 \ldots . p_n = P$. Ecology Control has found that p as measured is considerably less than the calculated P, using p_o for each component. Thus k_i is less than p_o for each component.

McGill[10] has pointed out that the oil can add vapors to the scrubber emissions when the hydrocarbon vapor concentration from the barge is very low. This can happen when new diesel oil is used or the oil is not completely regenerated. Ecology Control states that new diesel oil does contain volatile hydrocarbons which are foreign to the main composition. However, on one or two cycles these are completely removed from the oil and subsequently the oil is nonvolatile within practical limits of measurable vapor concentration.

Table 7 gives pertinent properties of a few of the main components of diesel oil.

TABLE 7. DIESEL OIL

Hydrocarbon	Liquid Density g/cc	B.P. °C	Vapor Pressure, mm Hg @ 4°C	@ 93°C
Pentadecane	0.77	270	0.08	2.0
Hexadecane	0.77	287	<0.08	1.0
Heptadecane	0.78	303	--	0.6
Octadecane	0.78	306	--	0.4
Nonadecane	0.78	330	--	0.1
Eicosane	0.79	343	--	<0.1

Ninety percent of diesel oil No. 2 distills in the 280 to 340°C temperature range; approximaely 10% is then heavier than eicosane. The flash point is 52°C.

The regeneration is quite rigorous at 93°C and 150 mm Hg vacuum. It is sufficient to maintain absorptive capacity of oil to the level that

the 80 mg/liter concentration is achieved. If necessary, the regeneration can be made more rigorous by increasing temperature and decreasing vacuum, and thereby desorb virtually all volatile vapors from the oil.

The use of two oil storage tanks gives the system some versatility. If barge loading is infrequent, for instance one barge a day, the oil regeneration part of the unit can be small but the oil tanks have to be large enough to last the 190 minute loading time. Regeneration is started at the same time barge loading starts but can continue for 24 hours, the time when the next barge will be ready for loading. During the 24-hour period, the lean-oil tank has been refilled. If a large number of barges need to be loaded in succession, the regeneration capcity must be large enough to keep up with exhaustion rate of the oil. In this case, the oil storage tanks can be small, but the regenerated part of the unit large. Since mechanical equipment is considerably more expensive than tankage, initial capital investment can be considerably reduced by increasing tank size and decreasing regeneration equipment size to the degree that the loading schedule permits.

Ecology Control has recommended for this application a unit that can regenerate at the rate of about 30 liters/min and tankage to hold 45,600 liters of oil. This unit when used to its full capacity can handle the loading of two barges in succession, but 30 hrs of regenerative time are then required. However, it has 22,800 liters of over-capacity if a barge were loaded each day. About 15 hrs of regeneration time would be required.

Ecology Control does not supply instrumentation with the unit, so that continuous logging of influent and effluent vapor concentrations cannot be performed. It is up to the user to supply instrumentation or have periodic checks made on the efficiency of the unit.

Economic Analysis

Table 8 presents an estimate of operating costs (in 1979 dollars) of each type of vapor recovery system. In each case the manufacturer was contacted for type, size and cost of a skid-mounted vapor recovery unit recommended for this particular application. The breakdown of the cost

TABLE 8. OPERATING COSTS PER YEAR (1979 dollars)

	Adsorption	Refrigeration	Oil Absorption
Capital	$44,500	$46,300	$26,600
Electricity	7,800	8,000	7,400
Maintenance & Labor	9,000	15,000	9,000
Administrative	9,200	10,400	6,400
	$70,500	$79,600	$49,400

figures (in 1979 dollars) is given in Tables 9, 10 and 11. The carbon adsorption and refrigeratin units are of size that could handle consecutive barge loading indefinitely with one to two hours lapse time between each loading. The oil absorption unit can handle two consecutive barge loadings every other day or one loading each day. The annual costs are based on 300 loadings.

A vapor line of about 10 meters is assumed sufficient to connect barge to vapor recovery unit.

The fixed capital costs vary between $166,000 and $292,700, the lowest being the oil absorption unit. It has the limitation that it can handle only one barge a day. If it were enlarged to a size that could handle consecutive loadings, its capital cost could be quite close to those of the other two.

The major factor in the annual costs is the amortized initial investment. The oil absorption unit has the lowest annual operating cost. Maintenance and labor were rated higher for the refrigeration unit because of the reported higher labor skills and parts cost for the compressors used in the coolant loop of the refrigeration system.

For the present application, the most economical unit is the oil absorption. With change in ground rules, such as indefinite number of consecutive loadings, a new evaluation may be necessary. Then selection may become the preference of the user for a specific barge loading situation.

Table 12 shows the various steps involved in calculating the cash credit from recovered vapors condensate valued at $0.13/liter. This was the price of gasoline when the equipment cost figures were obtained. While the cost of gasoline has risen substantially, so have the equipment, interest and operating costs. The cost figures should, therefore, still be valid on a relative basis. The $78,000 is a credit which can recover the capital investment in 5.8 years for oil absorption and 37.6 years for carbon absorption. The $78,000 credit is less than the operating costs of the refrigeration system and no payback is possible.

The costs reflect a fairly simple straightforward vapor control installation. The capital costs do not include ship to shore transfer arms, dockside materials, off-dock piping, process unit materials/flame arrestors, dock renovation, land preparation and engineering. The operating costs do not include additional material, taxes, insurance or labor. These additional costs will most likely be incurred as a result of site-specific con-ditions.

The overall cost analysis should also include the cost to modify the barges for vapor collection. Cost of barge modification is borne by the barge owner but he is not in position to receive any of the cash credit. if the barge modification is included in the above cost figures, it will take considerably longer to recover the initial capital investment.

TABLE 9. ACTIVATED CARBON UNIT (1979 dollars)

Fixed Capital

Skid mounted unit, Model 1004	$267,100
Concrete pad	2,700
Electric feeder	5,000
Freight	3,000
Rigging, crane & men @ $175 for 8 hr	1,400
Vapor piping to unit	10,000
Parts inventory	3,000
	$282,200

Yearly Capital Costs

10% annual interest rate on invested money for 15 years equipment life and capital recovery factor of 0.131.

282,000 x 0.10 =	$ 28,200
$\frac{282,000\ (1-0.131)}{15}$ =	16,337
	$ 44,537

General and Administrative

15% of other yearly operating costs

0.15 x $61,300 =	$ 9,190

Electricity

61.7 KW x 3 hr (load) + 4 hr (add.) =	432 KWH
432 KWH x $0.06/KWH x 300 barges/yr =	$ 7,780

Maintenance & Operating Labor

Based on $15/hr and 600 hr =	$ 9,000

The costs reflect a farily simple straightforward vapor control installation. The capital costs do not include ship to shore transfer arms, dockside materials, off-dock piping, process unit materials/flame arrestors, dock renovation, land preparation and engineering. The operating costs do not include additional material, taxes, insurance or labor. These additional costs will most likely be incurred as a result of site-specific conditions.

TABLE 10. REFRIGERATION UNIT (1979 dollars)

Fixed Capital

Skid mounted unit, Model 4800 P	$264,600
Concrete pad	2,700
Electric feeder	5,000
Freight	3,000
Rigging, crane & men @ $175 for 8 hr	1,400
Vapor piping to unit	10,000
Parts inventory	6,000
	$292,700

Yearly Capital Costs

10% annual interest rate on invested money for 15 years equipment life and capital recovery factor of 0.131.

$292,700 x 0.10 =	$ 29,270
$\frac{\$292,700 \times (1-0.131)}{15}$ =	16,960
	$ 46,230

General and Administrative

15% of other yearly operating costs

0.15 x $69,200 =	$ 10,380

Electricity

140 KWH x 3.16 hr (load) =	442 KWH
442 KWH x $0.06/KWH x 300 barges/yr =	$ 7,960

Maintenance & Operating Labor

Based on $15/hr and 1000 hr =	$ 15,000

The costs reflect a farily simple straightforward vapor control installation. The capital costs do not include ship to shore transfer arms, dockside materials, off-dock piping, process unit materials/flame arrestors, dock renovation, land preparation and engineering. The operating costs do not include additional material, taxes, insurance or labor. These additional costs will most likely be incurred as a result of site-specific conditions.

TABLE 11. LEAN-OIL ABSORPTION UNIT (1979 dollars)

Fixed Capital

Skid mounted unit, 15,899 liters cap.	$115,500
Concrete pad	2,700
Electrical feeder	5,000
Freight	3,000
Rigging, crane & men @ $175 for 8 hr	1,400
Two 64 m tanks with concrete pad	14,600
45,600 liters No. 2 oil	10,800
Vapor piping to scrubber/absorber	10,000
Parts inventory	3,000
	$166,000

Yearly Capital Costs

10% annual interest rate on invested money for 15 year equipment life and capital recovery factor of 0.131

166,000 x 0.10 =	$ 16,600
$\frac{166,000\ (1-0.131)}{15}$ =	9,600
	$ 26,600

General and Administrative

15% of other yearly operating costs

0.15 x 43,000 =	$ 6,400

Electricity

29.3 KW x 3 hr (loading time) + 11 hr (add. regeneration) = 29.3 KW x 14 hr =	410 KWH
410 KWH x $0.06/KWH x 300 barges/yr =	$ 7,380

Maintenance & Operating Labor

Based on $15/hr and 600 hrs =	$ 9,000

The costs reflect a farily simple straightforward vapor control installation. The capital costs do not include ship to shore transfer arms, dockside materials, off-dock piping, process unit materials/flame arrestors, dock renovation, land preparation and engineering. The operating costs do not include additional material, taxes, insurance or labor. These additional costs will most likely be incurred as a result of site-specific conditions.

TABLE 12. CREDIT FOR RECOVERED GASOLINE

Emission factor uncleaned barges [1]

.454 kg/1000 liters (3.8 lbs/1000 gallons)

.454 kg/0.62 kg/liters = .732 liters

(.90)* (16,000 liters/min) (.732 liters/1000 liters)
(190 min/barge) ($.13/liter) = $260/barge

(300 barges/year) ($260/barge) = $78,000

*Assume 90% recovery efficiency due to leaks and vapor recovery unit performance.

Recovery Unit Safety

The three recovery units (carbon adsorption, oil absorption and refrigeration) do not differ significantly in regard to safety although some observations and theoretical views can be expressed here to give a more complete coverage of the safety aspects. The air-vapor mixture entering the carbon bed, condenser, or absorber can be in the explosive range (1.5 to 7.6%) although in barge loading it is expected to be 12 mol % or higher most of the loading time. The secondary or effluent hydrocarbon emission concentrations from the three units range from 30 to 80 mg per liter. In terms of vapor volume percentages, the concentration range is 1.2 to 3.2 These percentages are for propane and higher molecular weight hydrocrbons. If a few percent of methane and ethane, which are usully present, are added to the 1.2% and 3.2% figures the secondary emissions are invariably in the explosive range. Within each sorber or condenser, the concentration then passes through the explosive range.

Activated carbon is a fairly good conductor of electricity, hence static electricity cannot be a probable source of ignition. Carbon is also a poor adsorbent for moisture and thereby moisture will not be removed from the gas stream. This further minimizes the possibility of static electricity. Because of the void space and carbon mass, the bed can act as a flame arrestor. However, it has been reported that certain ketones or other organic vapors that can form peroxides have started fires in solvent recovery systems at the termination of the adsorption phase of the adsorption-regeneration cycle. Spontaneous combustion is not probable because analyses of gasoline vapors do not show peroxide-forming compounds. In addition, air during vacuum regeneration is quickly removed from the carbon bed.

Low temperature condensers produce very dry air-vapor mixtures, a favorable condition for generation of static charges which could ignite the mixtures. Within the finned section of the condenser, where the gas is the driest, static charge buildup is not probable because of the metallic fin surfaces. In the vent line where metallic surface area is smaller, the probability of charge buildup is greater although the low temperature could prevent any discharge from reaching the ignition temperature. The condenser can also function as a flame arrestor.

The lean-oil used in the oil absorption unit has a low electrical conductivity, hence static electrical charges can build up in the absorber and could ignite the gasoline vapor. Ecology Control has crossed the adsorber with metallic wire to dissipate any charge formation to the absorber shell. The oil does not remove moisture from the air-vapor mixture, hence conductivity due to moisture is retained. As was the case with the carbon bed and condenser, the absorber also can function as a flame arrestor.

The carbon adsorption unit has been in use since 1977, the refrigeration unit since 1974, and the oil absorption since 1972. No reports of vapor ignition involving any of the units have been reported thus far.

In regard to fabrication and construction, the three units meet ANSI, ASME, UL listing and ASTM standards. In addition, the support parts of the refrigeration and absorption units can be removed to a safe distance from the dock or storage tank areas, where gasoline vapors could escape into the atmosphere and produce a hazard in case of malfunctioning electrical equipment.

SELECTION OF VAPOR CONTROL SYSTEM - TASK 3

Approach

The approach for the selection of vapor control systems for barge loadings was to:

1. Make gasoline transfer with vapor control as safe as existing transfer operations.

2. Minimize pressure drop through the vapor collection system.

3. Eliminate as much as possible the use of blowers or other operational equipment.

4. Minimize capital and operational costs.

Presently, the transfer of gasoline by barge is done by fairly simple procedures. No inerting systems are used to make the residual vapors in the barge nonexplosive. While the barge is filling with gasoline, the displaced vapors are simply vented onto the barge deck.

Venting these vapors through a vapor control system would most likely result in a safer venting location because of the height of the vapor control outlet. However, the possibility of over or underpressurization of the barge is increased.

By placing the vapor control unit as close as possible to the barge, vapor piping is minimized reducing the pressure drop. Reduced pressure drop minimizes the need for blowers or other air movement equipment and sensors.

Barge Filling Procedures

Presently, to prevent rupture and/or explosions, the barge is loaded with the ullage caps or manhole covers opened. The vapors are exhausted from each of the barge tanks as it is filled. As long as the tanks are open, no overpressurization or vacuum can occur. The diameter of the manhole covers is such that there is little pressure drop across the opening. The barge operator can visually monitor the liquid level in the tanks by looking into the open cover. The vapors therefore are exhausted onto the barge deck. Measures taken to prevent explosion are fairly simple. The

barge dock is posted with no smoking and flammable vapor signs. Nonsparking tools may be used as well as a flame screen over the open ullage cap. If a liquid overflow occurs, the excess will flow out of the barge through the ullage cap onto the deck.

Vapor Collection Safety

As indicated earlier, if the vapors are to be collected and controlled, the present method of opening ullage caps is not acceptable. The collection of the vented gasoline vapors requires a closed system. A closed system will then require a number of measures to prevent barge rupture and/or explosion.

Since the operating pressure range to prevent rupture is small, the pressure drop through the vapor collection system and the vapor control unit should be minimized. This is the reason for large diameter piping and valves, and a direct reading level indicator on each tank as well as a high level alarm to shut down the filling process in an emergency. To verify the proper operation of the level gauges, a sight glass may also be recommended. Liquid spill valves should be used as a last resort, should all level indicators fail and liquid overflow occur. A pressure/vacuum relief valve should also be included in the vapor collection line to back up the existing P/V valves already on each tank.

Although it will probably not be possible to arrange during the field demonstration, future barge filling operations which include vapor collection and control may be done similar to truck and rail car filling operations where the amount of gasoline loaded is metered. The metering of gasoline during loading will eliminate the need for some of the level devices. While liquid meters exist for lower flow rates, they may not be practical for flow rates greater than 4000 liters per minute.

If an alarm is used to stop the loading operation, the pump and shut-off valves must be designed to prevent mechanical shock or liquid hammer on shut-down.

If the vapor lines are short, movement of the vapors from the collection system to the control unit can be done by internal pressure solely from displacement during filling. Fans or blowers could become a source of ignition, as well as potential for creating a vacuum on the barge. If the vapor control unit is close to the barge, the total pressure drop through the collection system and the control unit can be low enough so that a fan or blower is not necessary.

To prevent propagation of flames back to cargo tanks, arrestors tested and found effective for in-line service should be used at shoreside vapor line connections. The U.S. Coast Guard [12] has tested several devices for this application. Flame arrestors should also be placed on the outlet of the control unit since a flammable mixture could be emitted.

If vapor lines are short, safety modules which inert, saturate or dilute the vapors as they leave the barge may not be necessary, and in fact

increase the amount of equipment located at the dock which can be potential ignition sources. Treatment of gasoline vapors as soon as they exit the barge can eliminate long vapor lines and safety modules.

To date, the large number of vapor control units installed at truck loading terminals, where the vapor concentration is usually well above the explosive range, do not have safety modules. However, the vapor concentration will be closer to the explosive range at barge loading facilities.

At present, a closed vapor collection system with inerting is installed at Corpus Christi, TX for loading benzene. The vapor collection and control unit has not been used. Therefore no operating experience is available to evaluate this system.

Safety Modules

Prior analyses[7] of gasoline vapor control at barge loading operations suggested the use of safety modules to reduce explosion or fire hazards. These safety modules are inertion, saturation or dilution.

Inert gas systems provide a low oxygen cover gas which prevents vapors in the explosive range from igniting. As the barge is being unloaded, the inert gas would be piped into the ullage space. Upon return of the barge for refilling, the vented vapors could be sent through the vapor control unit.

The inert gas could be CO_2 from a combustin process or nitrogen from a storage area. The gas inerting system would therefore need to be installed at unloading facilities. Inert gas systems will require a fuel source if CO_2 is the cover gas.

Inerting systems using carbon dioxide are combustion systems requiring commensurate safety controls. Failure of these systems could create a hazardous exhaust. The inert gas systems using nitrogen require storage areas and piping. Replacing the gasoline liquids as they are removed from the barge also requires a closed system, adding to possible over/underpressurization of the barge.

Saturation units use a supply of gasoline, propane or natural gas to increase the flammable vapor concentration above the explosive limits. Only gasoline can be used in the saturation unit with vapor recovery. Propane and natural gas will not be removed in any vapor recovery system to any degree. As a result, the goal of only 80 mg/liter of hydrocarbons would be exceeded unless these lighter hydrocarons were excluded from this standard.

Using gasoline in vapor recovery equipment will increase the load on the equipment, with the greatest effect on the oil absorption system. The oil and carbon sorption systems would have to be larger. However, the refrigeration system is generally sized for an air flow and not a vapor

concentration since most of the cooling is required to chill the air. It is possible to volatilize over 4000 liters in saturation unit during the unloading of a 3140 m^3 barge. However, the gasoline from the vapor recovery unit could be recycled to the saturator.

Saturation with incineration would use additional fuel with no chance of recovery unless the waste heat could be utilized.

Saturation systems can result in a hazardous situation if they fail. Additional equipment is required to move the vapors through the saturator. In the extreme, during very cold weather, it is even possible for saturated concentrations of gasoline vapors to be in the explosive range.

Dilution systems decrease the gasoline vapor concentration below the lower flammable system. The dilution system would increase the total gas flow to the control unit by at least 100 times. This would greatly increase the size of the vapor collection system. In addition, because of the low hydrocarbon vapor concentration (<1.4%), recovery systems would not be possible and incineration would require large amounts of auxiliary fuel to oxidize the vapors in a huge volume of air.

It appears the use of safety modules will significantly increase the cost of vapor control systems and maintenance with no offsetting safety advantages for short vapor runs. For longer vapor lines they must be considered.

Passive Safety Equipment

While the use of active safety equipment appears to be an unnecessary expense with no offsetting safety benefits (for short vapor lines), additional safety measures must be taken to prevent accidental damage to the barge and shore facilities.

The most likely event to cause damage is over/underpressurization of the barge. Active safety modules appear to increase this risk, because of the use of blowers. Passive safety equipment is available which can be conveniently used in a simple vapor collection system and yet significantly increase the margin of safety. Passive safety equipment includes flame arrestors, P/V valves and overflow alarms, all of which can be placed in vapor collection lines.

Flame arrestors are available in a variety of configurations. A recent report by the U.S. Coast Guard [12] discussed tests where gasoline vapors were ignited in 15 cm piping to determine the effects on flame arrestors. It gives the conditions needed to produce a detonation in vapor piping as well as the flame arrestor design most likely to quench and withstand the detonation. The results of the USCG report are limited to 15 cm piping and should not be extrapolated to larger diameter piping.

Reference 12 indicates that upstream flame propagation is difficult when the gasoline vapor/air mixture velocity is greater than 1.5 m/sec.

However, reference 11 shows that for butane/air (gasoline vapors usually contain a high percentage of butane vapors), the mixture speed should be greater than 3.3 m/sec to prevent upstream propagation. The velocity of the gasoline vapors is 3.8 m/sec in 15 cm piping at 4000 liters/min and 15 m/sec at 16,000 liters/min. Because of the discrepancy in the data between butane/air and gasoline/air, the velocity in 15 cm piping, particularly at lower filling rates may not guarantee that a flame will not backflow through the vapor piping to the barge. During the start-up and shut-down when the velocity of the gasoline vapors in the vapor collection system is very low, the likelihood of flame travel through the vapor collection piping to the barge is evident.

The run-up distance needed for flame to detonation transition is 11.2 m for 15 cm piping. If the straight runs in the vapor lines are minimized, this length is not exceeded. This is facilitated if the vapors are treated as soon as possible after leaving the barge. Finally, the flame arrestor specified for the barge demonstration is one which sustained 9 detonations, successfully quenching the flame[12].

Since the test results indicate a flame may travel against the flow of vapors (in the collection line), safety modules will not provide protection between itself and the barge. Flame arrestors are necessary at the barge. Through the use of tested flame arrestors, safe containment and flame quenching should be possible without the need for safety modules.

Selection of Recovery System

The three vapor recovery units have been examined in regard to effectiveness, safety, capital and operating costs, and occupied space. There has been a continual upgrading of the units each year, hence the basis for criticisms leveled at any of the units could be corrected. There is no great superiority of one unit over the other in regard to effectiveness, safety or total occupied space. A nondebatable decision cannot be made on the selection of a particular technology as being best suited for barge loading. The carbon unit may have an edge on the other two if the required secondary emission levels were lowered from 80 to 35 mg/liter, as suggested in the December 17, 1980 Federal Register. The operating costs for the refrigeration and oil absorption units in this case would rise above those given in Table 8. If dock space is very limited, the refrigeration and oil absorption units would have the advantage, since the small condenser or adsorber can be located separately from the support unit.

Because barge loading at many terminals is done on an intermittent rather than continual basis, it was decided that the oil absorption unit would be the most economical choice.

The major obstacle to the use of vapor control at barge loading has been economics. Although there are claims of a good payback with recovery systems, no potential users are convinced enough to install such systems for the return on investment. The primary impetus for installation of existing vapor dispersal or collection systems at Corpus Christi, Marion Oil Company and Union Carbide is environmental. Therefore, when a company examines a barge vapor control system, it appears that low purchase and operating costs will determine which system is chosen.

Refrigeration was not chosen for the barge loading demonstrati for several reasons. First, the barge gasoline vapor emissions are in tion 5% to 15% range for almost 75% to 80% of the total loading time. Only the wards the end of the loading cycle do the hydrocarbons in the vapo approach 50%. The refrigeration unit would still operate at full capaci since the air must be cooled to a certain temperature regardless of ti hydrocarbon content. The air would be cooled with little resultant hydr carbon condensation for a large part of the loading. This could result excess energy consumption for the amount of gasoline recovered.

Second, the operating costs on the refrigeration system are hi because of maintenance. In many cases users arranged an outside servi contract to insure continued reliable operation of the refrigeration unit.

Carbon adsorption was also not selected because of its high in ial cost and the large space needed for the placement of the two large c bon beds. If the carbon beds were placed away from the barge loading ar long vapor lines would be required.

Incineration was chosen as a possible vapor control technique barge demonstration since it has low initial and operating costs. Howev only the incineration systems using a pilot flame (flares) look attract as opposed to burners where auxiliary fuel is constantly needed. The c of auxiliary fuel was high and unnecessary. Fire and explosion are a c cern with any incineration unit. A number of incinerators have operat safely at truck loading facilities. However, the vapors at barge load wil be closed to the upper explosive limit. Adequate flame quenching equ ment must be used to assure safe operation. In addition, no payback i possible.

The vapor recovery system which appeared to offer the best resu was oil absorption. The initial cost of oil absorption was lower than ot recovery units. The absorption tower could be conveniently mounted docksi on a crowded terminal site and the absorption oil piped to a remote reg eration unit. Short vapor collection lines could be used and the press drop through the system was low enough that no auxiliary blower was need The oil flowrate can be controlled based upon the percent hydrocarbons.

The payback for oil absorption was significantly less than car adsorption (5.8 years to 37.6 years). Refrigeration had no payback s operating costs were greater than the recovered value of the gasoline.

The oil absorption system, while the best in terms of costs a operation, may experience problems if the permissible level of emiss falls below 80 mg/liter

Selection of Collection System

As noted in earlier studies, the collection of vapors and the transport to the control system has not been a problem-free operation truck loading terminals. A particularly troublesome area has been va leaks at flanges, fittings, etc. This is compounded by the fact th

vapor collection is considerably more involved in barge loading because of:

1. Multiple vent lines
2. Higher loading rates
3. Movement of barge during loading
4. Exposure to adverse weather conditions (no roof over the loading area)
5. Greater diversity in barge construction
6. More than one type of fuel may be loaded onto any one barge
7. Dock space may be limited, preventing installation of necessary collection and recovery equipment near the barge loading area.

A collection system is needed to meet the above and additional demands, which:

1. Is leak tight under all loading conditions;
2. Will not start to leak after a few loadings and thereby need frequent maintenance;
3. Does not require a great deal of operator time, expertise, or hard manual labor to get the vapor collection system into operation (and again to disconnect all lines);
4. Does not clutter up dock area, and
5. Minimizes operator error.

The first requirement, however, is the prevention of vapor ignition, and if it should occur, to prevent its spread to adjacent equipment. The second requirement is the prevention of over or underpressurization of the barge.

Several methods of vapor collection have been considered. These are:

1. A system of fixed collection lines on the barge, connecting all tanks, and a single manifold to which one dockside connection can then be made.

2. A system of branched flexible collection lines stored on the dock but moved on board the barge by means of booms and then connections made to each tank.

3. Flexible collection lines, one for each tank, stored on the dock and moved individually and manually on board and connected to each tank.

In each case, the vapor is directed to a single manifold which then carries the vapor to the recovery unit.

Regardless of type of piping system used, a number of permanently attached fixtures are required on board the barge to make the collection systems workable. These are:

1. Liquid level gauges

2. Overfill warning system

3. Liquid spill valve

4. Pressure and vacuum relief valves on each tank

5. Flame arrestors.

Of the three piping systems, the first was the preferred, but the reason for initially considering the flexible line systems, 2 and 3, was that these methods may give greater flexibility in collecting vapors from a variety of barges. The minimum requirement to fulfill the scope of contract was 30 vapor recovery cycles over a 6-month period. By use of the flexible systems, it appeared at first that vapors could be collected from a variety of types of barges with minimal modification to each barge. On futher study, it became apparent that each barge would have to have all or most of the above protection devices which should be installed on a permanent basis.

Further study, involving sketches and other considerations, showed that the flexible line systems would be very cumbersome to handle and would require considerable dock space. The initial cost saved by using flexible lines would be quickly lost because of their greater manpower requirements.

The circumstances as outlined above dictated the use of a hard line collection system. The vapor lines must be metal as required by the U.S. Coast Guard. The above protection devices, as well as the metal lines, can be assembled by means of flanges and bolts or welded.

Hard Line System

The proposed collection system together with the location of the recovery unit is shown in Figure 5. The barge has eight tanks connected to a common vapor line terminating at edge of barge. A flexible hose or nonflexible connector with swivel joints connects the barge vapor line to the on-dock line leading to the absorber. A support unit off the dock area supplies the cooled lean oil to the absorber and regenerates the returned rich oil. The treated air is exhausted into the atmosphere from top of adsorber through a flame arrestor about 7.5 meters above the dock surface. Gasoline from storage is used to absorb the recovered gasoline vapor and the enriched gasoline returned to storage. Gasoline/condensed vapor ratio of 100 to 1 appears to be required. The other option is to condense the vapors by cooling with some compression and pump directly to storage.

The piping is permanently supported on the barge deck. Connections are made to each tank at existing Butterworth or ullage caps. A flame arrestor is located at the manifold to the flexible shore-side connection. An enclosed liquid level gauge for each tank is installed separately through the deck in the center of each tank. On deck for each tank is a pressure-vacuum relief valve; these are required on all gasoline barges presently in operation. The pressure relief valve operates at a pressure of 50 cm H_2O and at a vacuum of about 17 cm H_2O. The vapor recovery system operates at pressures below 30 cm of H_2O. The piping, valves and flame arrestors must operate in a fairly narrow pressure drop range to maintain pressure drop below 50 cm of H_2O. Pipe diameter recommended is 15 cm and distance to the absorber less than 10 meters. It is, therefore, desirable to have the absorber on the dock, as close to the barge loading area as possible.

Safety Aspects

Safety is the most important consideration in the evaluation of a vapor collection and control system for barge loading. An accidental rupture or explosion would in all probability result in loss of life and property.

The areas of greatest danger in controlling gasoline vapors are barge rupture and/or explosion. Barge rupture could occur when the barge is overpressurized because of blocked vapor relief vents or liquid overfill. Rupture can also occur if a blower creates an internal vacuum. The safe limits for most barges are 100 cm H_2O for pressure and 35 cm H_2O for vacuum. Clearly, these limits do not allow much leeway. Explosions can occur as the result of ignition of the flammable gasoline vapors which are exhausted during the barge filling process.

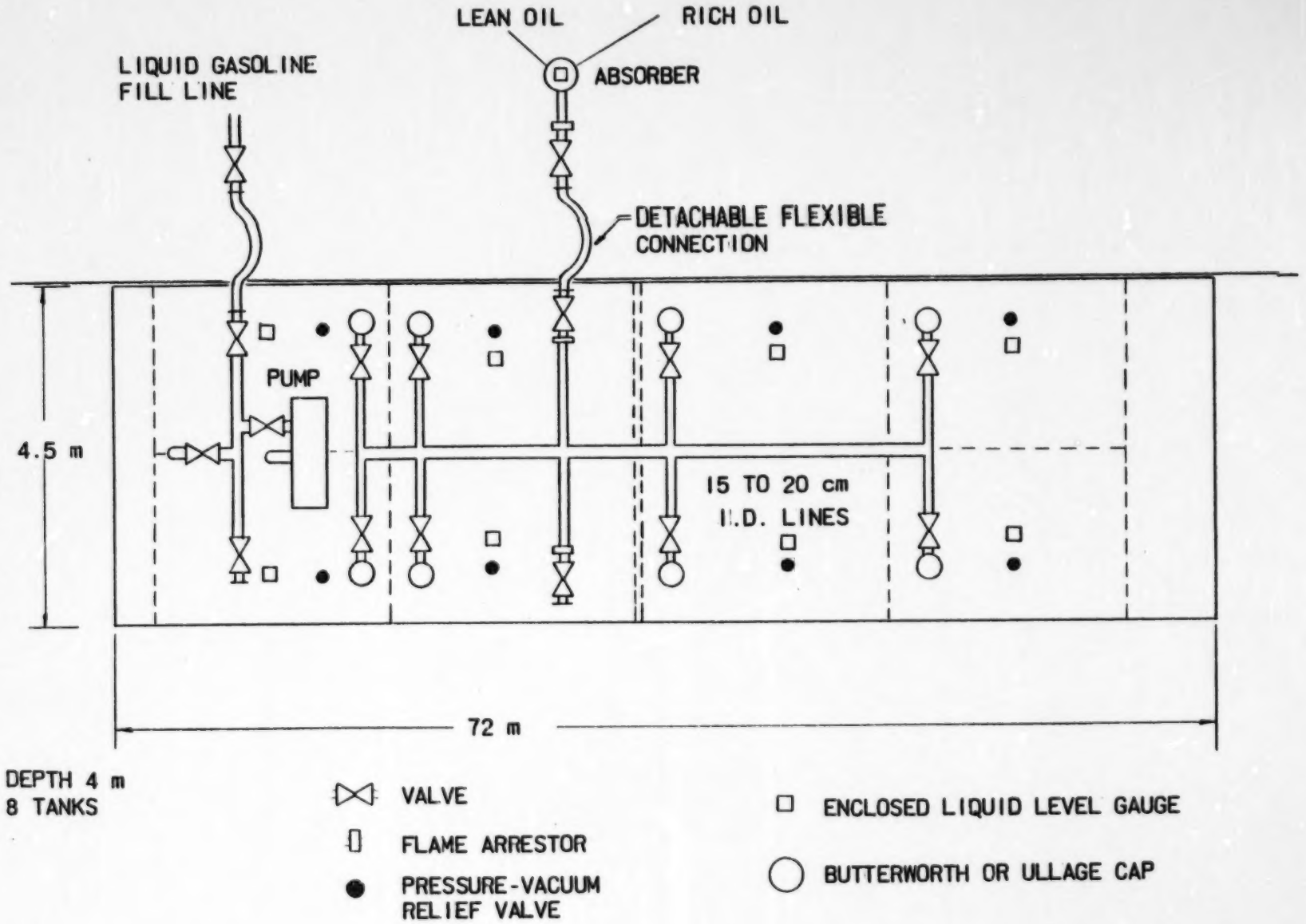


FIGURE 5- PLAN VIEW OF BARGE VAPOR COLLECTION SYSTEM

MARINE TERMINAL AND BARGE SELECTION - TASK 4

While terminal sites throughout the country were originally considered, a number of barge terminals were found which transfer gasoline in the Pittsburgh area. The advantages of operating in Pittsburgh were proximity and opportunity to conduct the field demonstration during warm and cold weather.

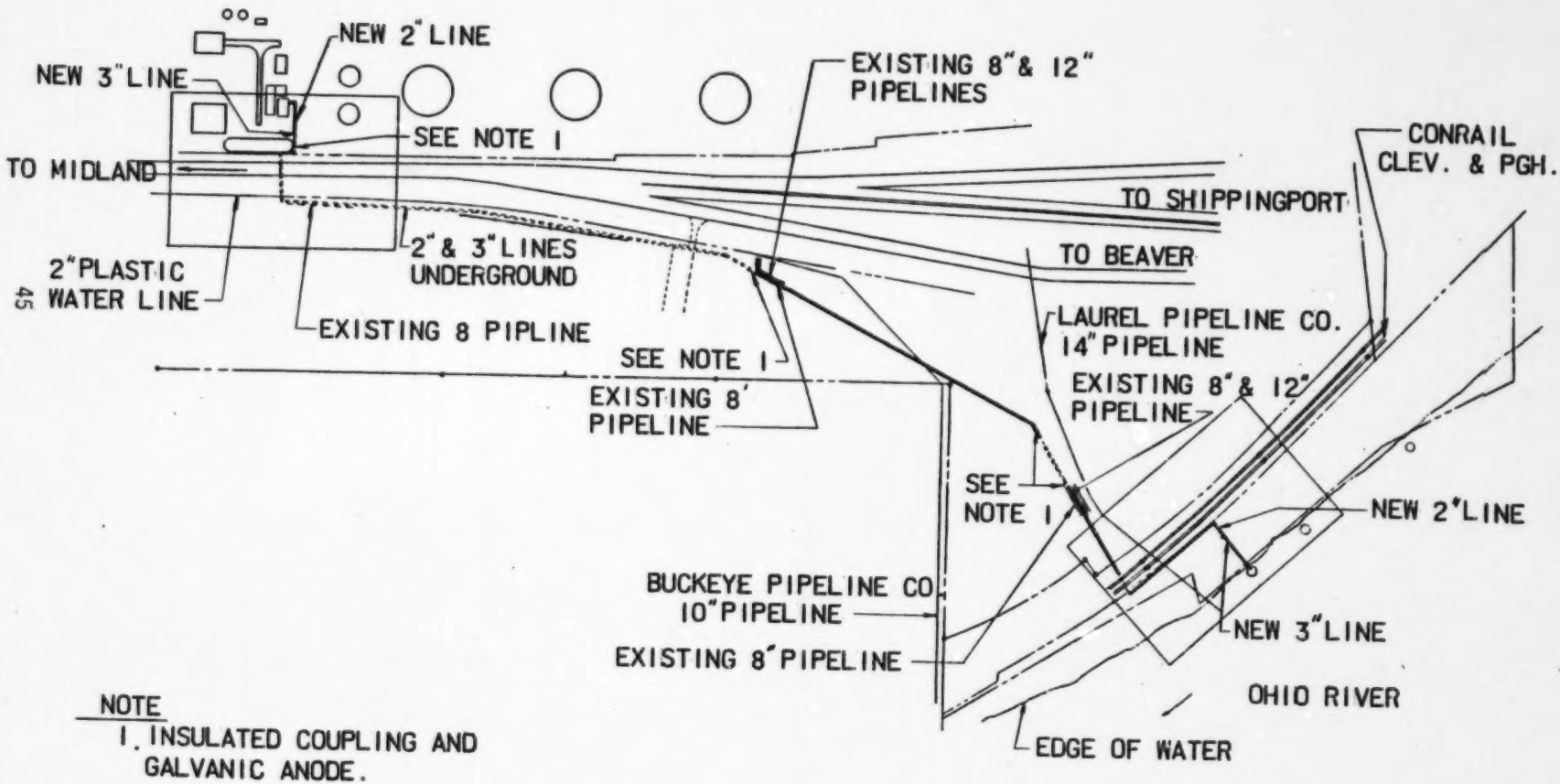
Three terminal sites were examined and a tentative cooperative agreement reached with the terminal operators. Subsequently, one terminal operator decided to withdraw from the agreement. Of the two remaining terminals, one appeared to be an excellent choice for the field demonstration.

At their Midland, Pennsylvania terminal on the Ohio River, Pennzoil has a gasoline barge loading terminal as shown in Figure 6. When Pennzoil purchased an oil absorption vapor recovery system to control gasoline emissions at the truck loading rack, they sized the unit to also handle emissions from the barge loading area in anticipation of future more stringent environmental regulations. While the barge loading portion of the vapor control system was not installed, the absorption tower for the barge loading site was purchased and stored on site. The barge facility handles several barges weekly and has a maximum fill rate of 10,000 liters per minute.

The portion of the gasoline vapor control system which was already installed included the rich and lean oil tanks and the regeneration unit. In order to make the barge portion of the vapor control operational, only the absorption tower and the rich and lean oil lines from the respective tanks to the tower had to be installed.

This is the type of system which MSAR recommended from the study of various methods of vapor control. It offers considerable flexibility in that the scrubbing unit can be located where most advantageous, and the lean oil can be pumped to the scrubber unit from another location. This reduces the run of vapor lines and thus enhances safety.

An unfortunate feature of the Pennzoil terminal is that the barge loading area is approximately 800 meters from the truck loading terminal, the oil storage tanks and regeneration unit. This necessitated sitting the presently unused scrubber at the dock, protecting it against vandalism by appropriate fencing, and running one 5 cm and one 7.5 cm oil line from the scrubber on the dock to the regenerating unit inside the truck loading area. Pennzoil already has a variety of gasoline product lines which run from the storage tanks located inside the truck terminal area to the dock. There is room on the pipe racks to accommodate the oil lines that must be installed for the scrubber. The rich and lean oil lines would be run from the respective storage tanks, under a road (Rt. 68), underground along the road for approximately 300 meters, then above ground down an embankment, under a railroad bed then above ground to the loading cell.



NOTE

1. INSULATED COUPLING AND GALVANIC ANODE.

FIGURE 6-PENNZOIL'S BARGE TERMINAL

A preliminary cost estimate for running the pipeline and mounting the scrubber was $100,000.

As a result of U.S. Coast Guard inquiries concerning safety, a terminal which could use incineration as the vapor control system was also sought to demonstrate operation and safety. A terminal owned by Boswell Oil Company was found in Dravosburg, Pennsylvania, approximately 16 km south of Pittsburgh along the Monongahela River. This terminal loads gasoline into trucks and barges. An incineration system was installed to control emissions from the truck loading rack and tank farm (Figure 7). Fortunately, the incineration system chosen by Boswell has enough capacity to also handle the vapors from barge loading. In order to connect the barge loading area to the incineration system, only the vapor lines had to be run with the required flame arrestors, pressure switches, knockout tank, etc. A preliminary cost estimate for this vapor piping was $40,000. This cost is substantially higher than the cost estimates given earlier for vapor recovery. The cost for the vapor piping to the incinerator system is higher for several primarily safety related reasons. The vapor lines to the incinerator are longer than for the vapor recovery systems. An array of four flame arrestors (to retain UL listing) are used instead of one in-line arrestor and the incinerator was upgraded to improve the operating pressure range and response of the incinerator.

The Boswell terminal vapor control system posed two interesting safety questions which were not inherent in the oil absorption design. The incineration unit requires a fairly long vapor line and the unit uses a blower and pressure switch to move gasoline vapors to the incinerator. It was felt that a successful demonstration at this facility would resolve many of the questions posed by industry concerning vapor control at barge loading terminals. There were also those in industry and the EPA who felt that incineration appeas to offer lower costs and greater convenience than the oil absorption system.

National Marine Service in St. Louis owns a number of double skinned, 1680 m^3, 3-compartment barges with vapor collection piping, spill valve, P/V valves set for 140 cm H_2O pressure and 35 cm H_2O vacuum, and remote gauging (Figure 8). One of these barges leases in the Pittsburgh area for approximately $285/day. Since we could lease an existing barge from National Marine Service with vapor collection piping and remote gauging, we would save the cost and time of retrofitting a barge without this equipment. However, some changes to the barge were required: an overflow alarm with warning lights and siren to back up the remote gauges and a flame arrestor in the vapor header.

It must be noted, however, that this type of fitted barge is the exception rather than the rule and that most barges used to transport gasoline do not have this equipment.

Discussions with the Coast Guard were held to insure regulations were being met. Their feelings were that the regulations were being met,

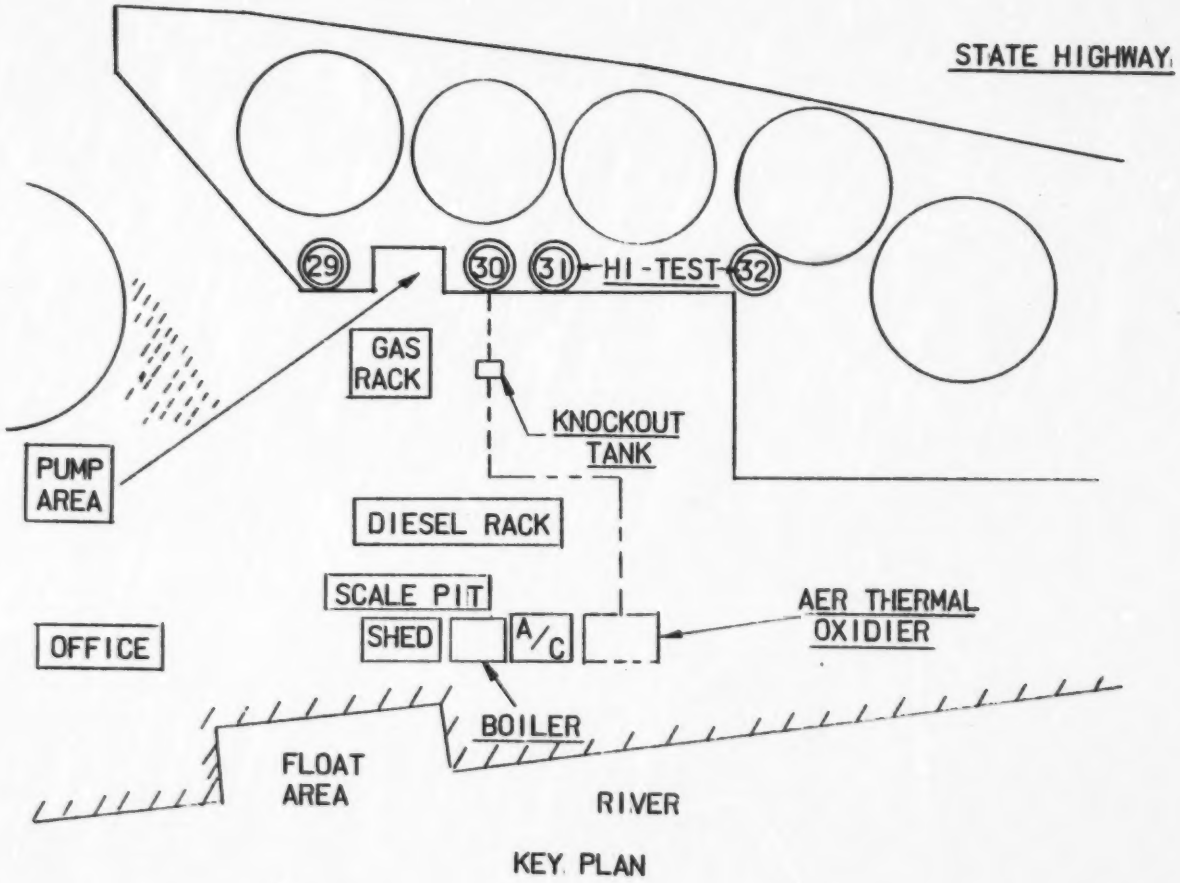


FIGURE 7-BOSWELL'S BARGE TERMINAL

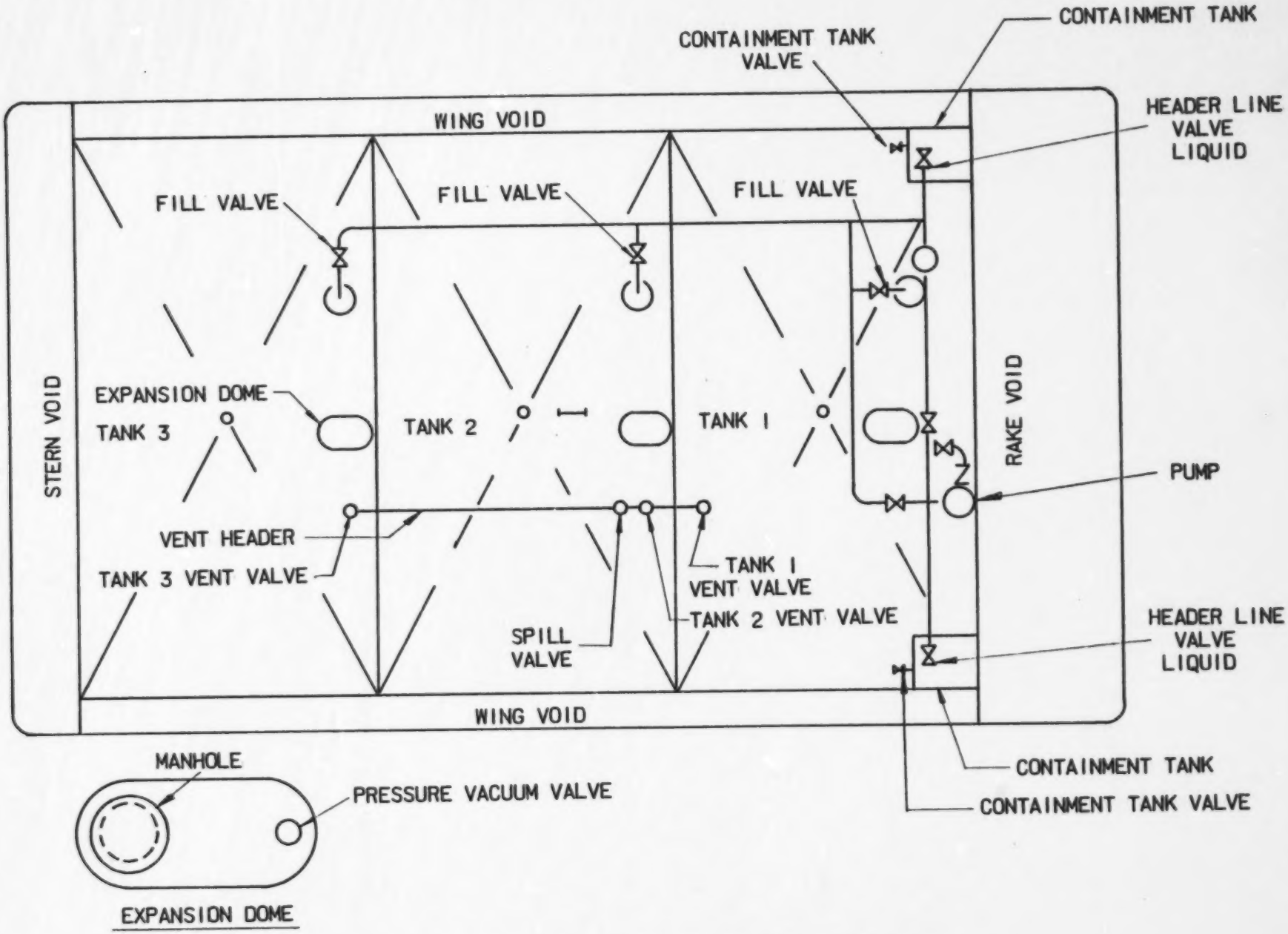


FIGURE-8 RENTAL BARGE CONFIGURATION

or exceeded. However, they would inspect any additional equipment on the barge even though it might not be required by Coast Guard regulations.

The Coast Guard has no regulations relating to on-shore vapor collection and control systems. However, since the terminal is nearby and thus could possibly affect barge operations, the Coast Guard does have the authority to prevent the terminal from operating if they feel an on-shore system endangers barge operations. The Coast Guard will review a proposed design for safety, and recommend needed changes.

The barge must have a Certificate of Inspection and it is necessary to furnish a Certificate of Financial Responsibility in order to cover the possibility of spills. Product transfer procedures are reviewed by the U.S. Coast Guard and are placed on the barge for references by the barge operating crew. A certified tanker man must be on the barge during transfer of products and it is necessary to also have someone on shore.

Tentative agreements were made to conduct the field demonstrations at Pennzoil and Boswell. Formal agreements had to await final design of the barge vapor control systems.

National Marine Service also assured availability of a barge with vapor collection piping when preparations were completed for the field demonstrations.

A preliminary design of the Boswell and Pennzoil facilities was presented to a Technical Advisory Committee formed to provide input to the program. The Technical Advisory Committee was made up of representatives of the EPA, Coast Guard, American Petroleum Institute, barge operators and several oil companies.

INSTALLED VAPOR CONTROL SYSTEM - TASK 5

With the approval of the EPA, final designs were prepared of the Pennzoil facility. Fabrication drawings were made and formal agreements signed with Pennzoil. In addition, written permission was obtained from the railroad to cross their right-of-way. A drawing of the barge loading area as it was planned is shown in Figure 9.

A sketch of the scrubber mounted on the loading cell is shown in Figure 10.

Because of an EPA funding reduction at this point, it was not possible to install the vapor control system at the Pennzoil terminal. It was therefore decided to install the incinerator vapor control system at the Boswell facility.

The system in Figure 11 was installed at the Boswell Oil Company's terminal in Dravosburg, PA.

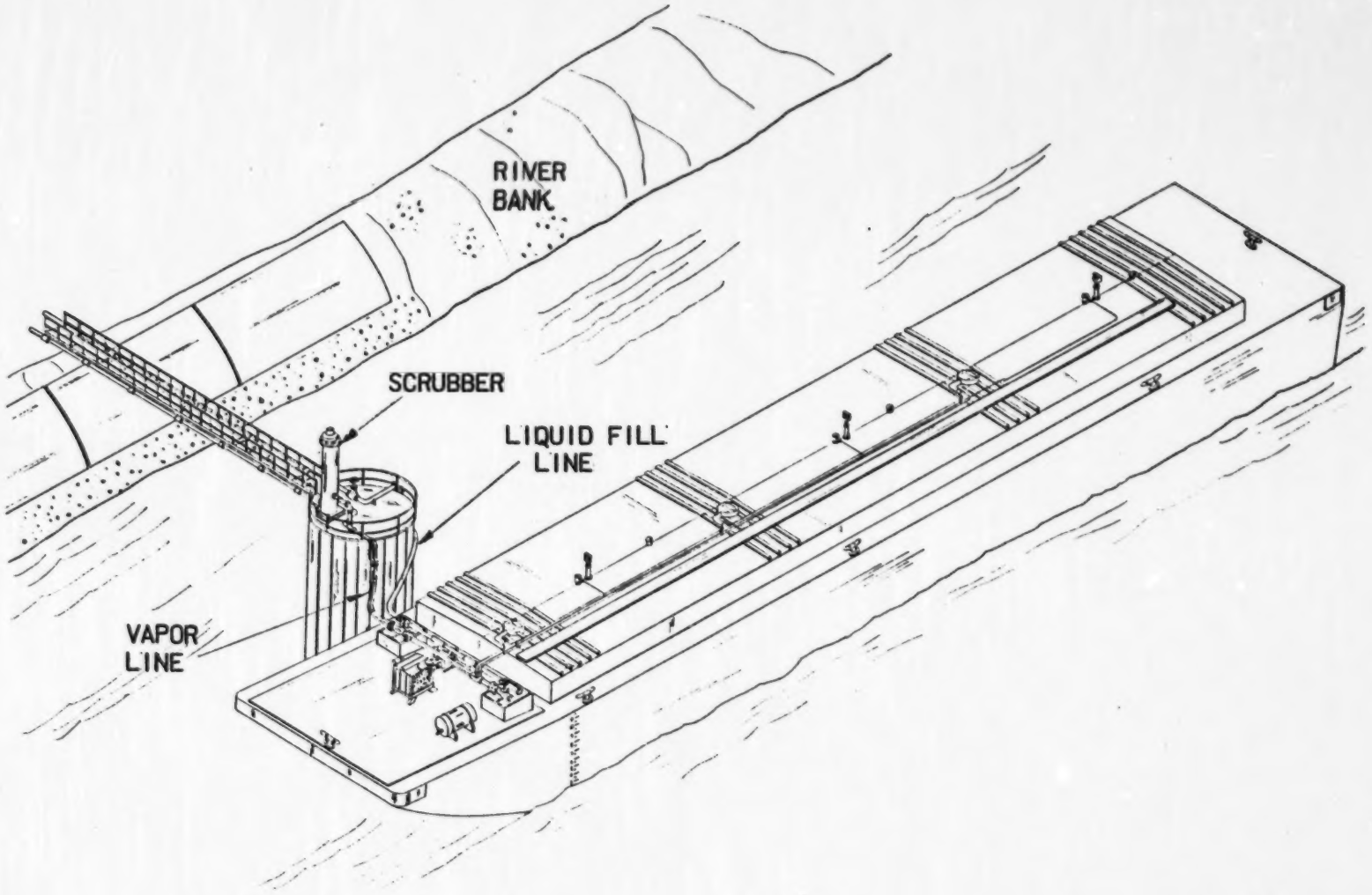
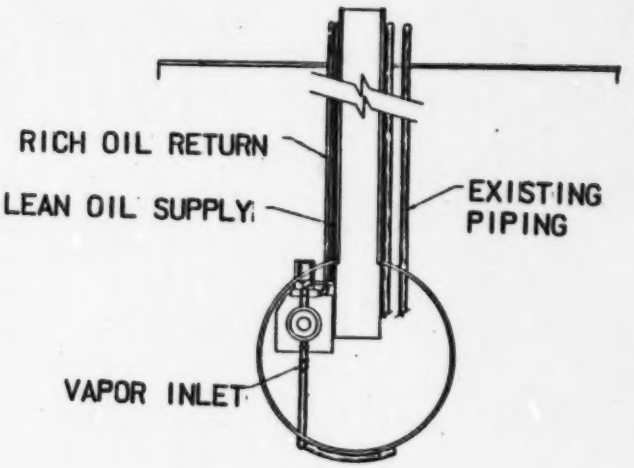


FIGURE 9 - PENNZOIL BARGE LOADING ARRANGEMENT



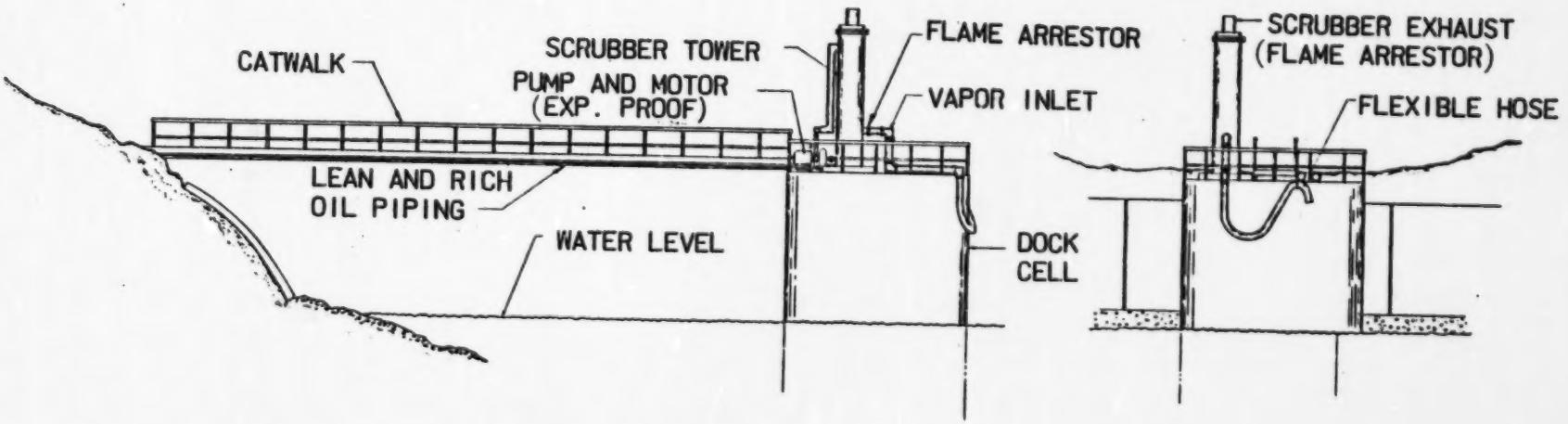


FIGURE 10-PENNZOIL'S LOADING CELL

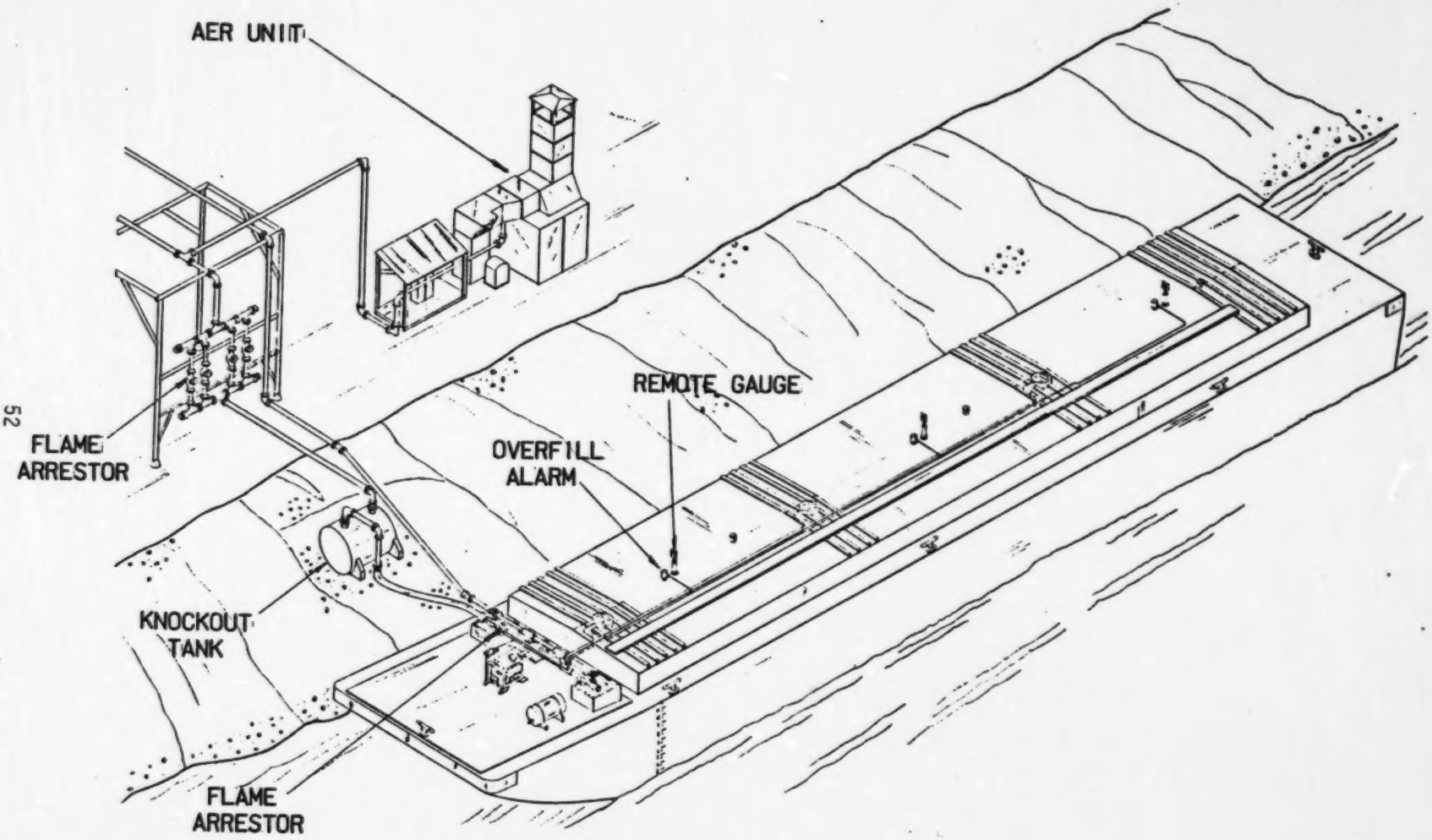


FIGURE 11-BOSWELL'S TERMINAL
INSTALLED VAPOR CONTROL SYSTEM

The on-shore system shown in Figure 11 includes the piping fro the barge to the incineration unit. The on-shore system includes a flexib hose section from the barge to the hard on-shore piping and through a knock out tank. From the knock-out tank the piping rises vertically through a array of flame arrestors. The piping then goes across a pipe rack to the 1 cm vapor piping. The barge loading rate is approximately 4000 liters minute. The actual cost of the installed on-shore vapor piping to the barg loading area was $31,000.

The system chosen by Boswell was sized to handle the truck, tan storage and barge loading areas. The incineratin unit has been in operatio approximately 5 years with no problems, servicing only the truck loading ar tank storage areas. No vapor piping was run to the barge dock.

The incineration unit is a thermal oxidizer - Model 300, manufac tured by AER Corporation located in Ramsey, New Jersey. Several improve ments were made to the Model 300 to accommodate barge loading. The majo improvement was to change the pressure transmitter from pneumatic to elec trical and reduce its range from 0 to 38 cm water column to 0 to 25 cm t improve the sensitivity of the pressure transmitter and reduce the operatin pressure in the vapor line. The unit uses natural gas as a pilot flame.

The unit treats the vapors directly. No vapor holding tank i used. The unit is approved by Factory Mutual. A sketch of the system i shown in Figure 12. (13)

On stand-by with no loading taking place, the unit requires n pilot fuel gas or electricity. Just before loading a fan (not shown) i manually started which takes fresh air from 3.7 meters above the ground an purges the combustion chamber to remove any residual flammable vapors. After purging the pilot burner is ignited by a spark igniter. When a ultra-violet detector signals that the pilot burner has ignited, loading ca begin. This sequence takes less than a minute. As the barge is loaded, th pressure increases in the collection system. The pressure switch the simultaneously activates the pressure booster fan and opens the safety shut off valve and the isolating valve. The control valve regulates the flow o vapor to the burners and keeps the pressure in the collection piping betwee 0 and 25 cm water column.

When loading ceases,the pressure switch closes the isolating valv and opens the purge system valves to remove the remaining flammable vapors. Spring loaded automatic check valves are used to prevent flame travel bac through the piping.

Most of the current AER thermal oxidizer units are installed with out the vapor holders.

Since only the loading cycle was of concern and there was littl barge traffic at the Boswell Terminal, arrangements were made to load th barge, disconnect, reconnect and then unload the gasoline back to th

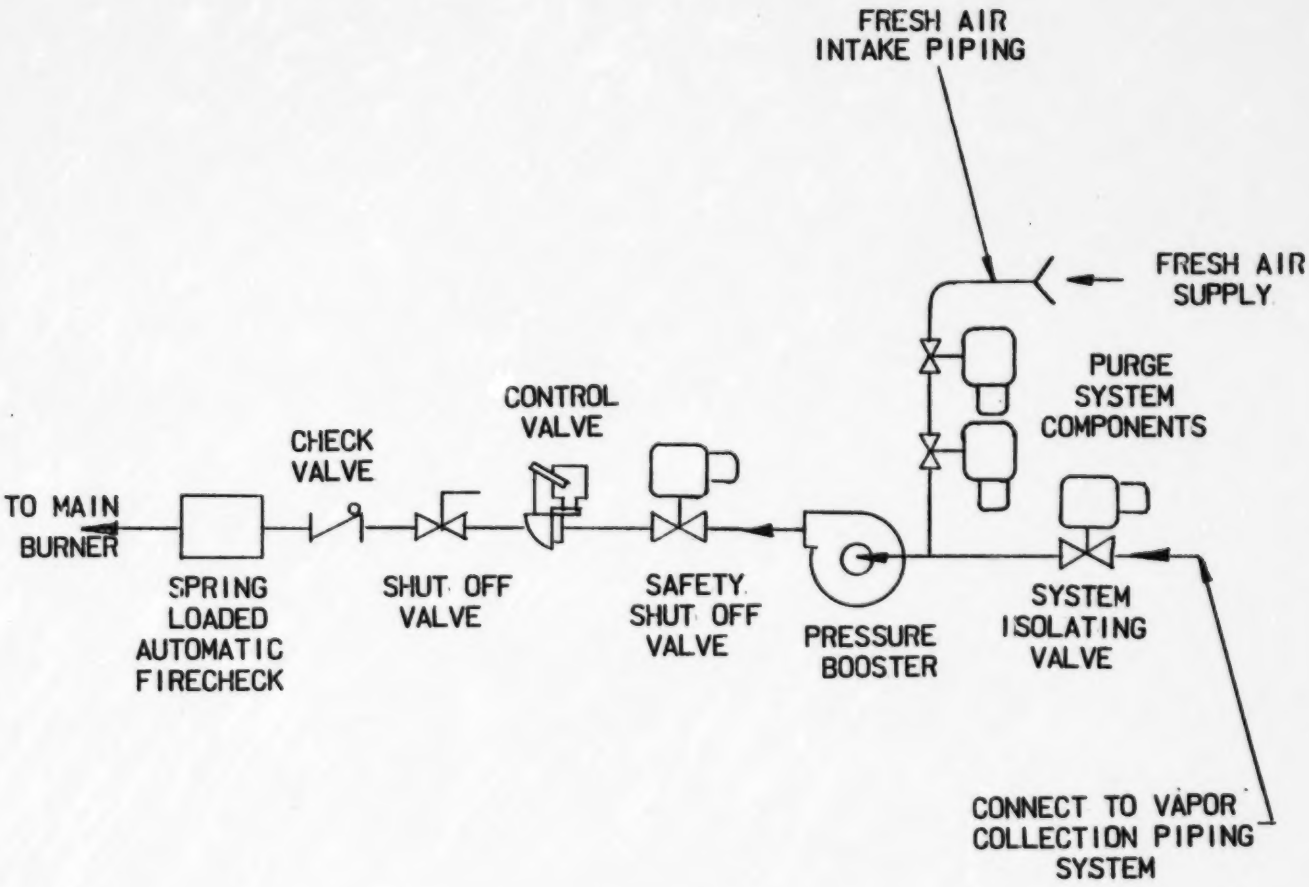


FIGURE 12-FLAMMABLE VAPOR INCINERATOR SYSTEM

storage tanks. Data wold be collected during the loading part of the cycle. It would take approximately 4 to 5 hours to fill the barge and 8 hours to empty. Because of funding reduction, it is expected 5 to 8 fill cycles could be performed.

The parameters to be measured were:

1. The volume of vapors (CFM) displaced from the barge during filling.

2. The percent total hydrocarbons in the vapors.

3. The amount of liquid gasoline loaded (gallons).

4. The total hydrocarbons in the incinerator exhaust (in ppm).

5. The approximate percent hydrocarbon at leak points in the vapor collection lines.

The data would be used to determine the amount of gasoline vapors emitted during barge loading, as well as performance of the vapor control unit. It is expected that the minimum performance of the incinerator will be an emission level which does not exceed 35 milligrams of volatile organic compounds per one liter of gasoline loaded.

The safety, economics, and emissions data would be used to evaluate the suitability of vapor control during barge loading of gasoline.

Installation of the vapor control system at Boswell's terminal was delayed due to their need to clarify the details of the agreement to conduct the demonstration at their facility. These details included consideration of insurance liability, compensation for costs involved in transferring gasoline, and their legal status as a result of cooperating in an EPA sponsored program.

These questions were eventually answered and the on-shore vapor piping was installed. A contract was signed with National Marine Service for the leasing of the barge and auxiliary equipment ordered. A Quality Assurance Plan also was submitted to the EPA for approval for the field demonstration.

Before the demonstration was scheduled to start, the EPA cancelled the program.

ANALYSIS OF RESULTS - TASK 6

Although no actual field tests were conducted, there are several interesting results which can be mentioned:

1) The cost of this particular installation was significantly less than earlier estimates since the vapor piping and incinerator were in place.

2) A larger incinerator could easily be installed with no major changes to handle 17 m^3/min (600 CFM).

3) There is no known area for heat recovery, so no payback is possible.

4) A larger terminal may have difficulties particularly if adjacent loading operations are being carried out. Since some gasoline loading is conducted in ships or barges where the vented vapors are in the explosive range, the proximity of the incinerator presents unacceptable safety hazards.

Difficulties

Many of the difficulties involved with the installation of the gasoline vapor control systems are of a nontechnical nature.

In the case of barge loading, the barge is usually leased. The question then becomes who is responsible for vapor control? Will the barge operator or terminal owner receive credit for recovered gasoline or pay for fuel in an incineration unit? Since it does not appear that a particular type of vapor control would be standard, how will the barge perhaps serving several terminals be affected by various control units?

Many legal problems could arise, primarily in relation to who is responsible for installation and maintenance of safety equipment.

Retrofitting barges with vapor collection systems will be costly. Placing vapor collection lines on a barges during construction is relatively inexpensive.

Additional training will be required of barge operators to familiarize them with the additional safety equipment and requirements.

Barge history will also be an area of consideration. Will a barge with a prior load of diesel be required to hook-up to the vapor control unit?

What will be the procedures in the event of vapor control unit malfunction? Delaying barge loading until the problem is corrected is costly and perhaps dangerous.

Because of the declining or flat gasoline market, some companies have considered closing their barge facilities and transport only by truck or moving the terminal to locations with no gasoline emission standards.

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